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# Transactions of *American Society* *for Steel Treating*

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Vol. IV

Cleveland, August, 1923

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No. 2

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# Transactions of American Society for Steel Treating

Volume IV

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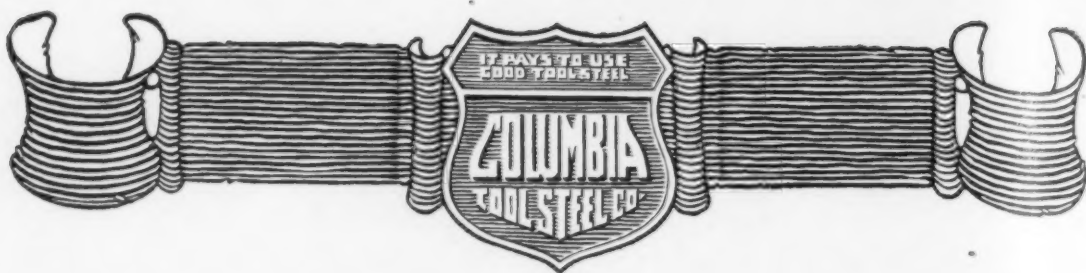
**4600 Prospect Ave.,**

**Cleveland, Ohio**

**R. T. BAYLESS, EDITOR**

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# *TRANSACTIONS*

*of the*  
*American Society for Steel Treating*

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## WAGES OR SALARY

IT IS quite frequently stated that the individual who receives wages has only a job; while he who receives a salary is considered to have in his possession a position. While the difference between a job and a position is of no degree of importance there is as a rule quite a wide and perceptible distance between wages and salary. For instance: a brick layer at \$18.00 to \$20.00 a day, a plasterer at a similar rate compare all to favorably with the skilled graduate engineer who must by force of circumstances and nonappreciation on the part of his employer go along on a salary of \$200.00 to \$250.00 a month.

We are always ready to grant the truth of the statement that the metallurgical profession is under paid. There are several prominent reasons that present themselves for this unfortunate and serious condition of affairs, the first of which is that metallurgy as a profession is rather new and consequently those employers of the old school are rather reluctant to grant the premises of a statement that a new profession has risen that performs a work of fundamental importance to his plant. The second reason for the small amount of the monthly pay check of the metallurgical engineer is that the engineer himself has failed to impress upon his employer the importance and responsibility of the position he fills.

On the books of any manufacturing concern you will find listed productive men and nonproductive men and it is unfortunate to observe that the metallurgical engineer is placed on the non-productive list. Consequently, when it is possible for one of the production men to place a chart before the manager showing that they have been able to increase production on certain machines 50 to

75 per cent it all makes a very favorable and profound impression upon the manager while undoubtedly it was not brought to his attention that the reason for this splendid increase in the efficiency of the machine was due to the solving of a problem by the metallurgical department.

We believe in giving every man his just dues, and we feel quite confident that the metallurgical engineer has not received his just dues, and that it is up to the engineers themselves to maintain a cost system in their own department and to charge up as productive labor all problems that are solved by their department which in anyway add to the efficiency of production.

Too many of our members are accustomed to hide their light under a basket, and while shouting your own praises or tooting your own horns are conditions that do not meet with hearty approval, nevertheless there are certain activities that the metallurgist concerns himself with that should be presented in actual figures and facts before the management. It is perfectly proper the metallurgist should receive a salary comparable in all respects to the the important and responsible position he occupies.

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### WHITE COLLARS

**C**ONTINUING the same line of thought as in the previous article, a large employer of labor recently stated his inability to employ men for responsible positions in the plant, while there was an over supply of white collared youths who were willing to take a clerkship at \$50.00 a month that offered no possibilities of any great advancement. One would be able to point without any strenuous effort countless individuals who have risen to great prominence in the business world who had their beginning among humble surroundings and conditions, but who realized their opportunities at that time, were only stepping stones to greater progress.

One thing that can be said of the metallurgical profession is that while it has men of the highest type many with college training, it also has individuals who understand and are willing to shed their coats and buckle down to the exigencies of the occasion in which they find themselves.

At the recent close of the commencement exercises of

American colleges and universities, 30,000 graduates entered into the world of business. There are those who discount the advantage of a college education, and when one considers the earning power of a college graduate as compared with a man who has learned a trade, there is some basis for doubt. However, all realize that while money is a very desirable commodity and a necessity in all activities, nevertheless it should not be the goal for which one strives.

There is a condition in living by means of which under the most favorable circumstances one is permitted to enjoy and live in harmony with everything around him, and it is all brought about in a most happy combination of conditions. While the college trained man starts in the race under a handicap of less practical experience, nevertheless, he has a better equipped mind and is able to make more rapid progress than the man who lacks scholastic advantages.

In this connection, the LeFax editors have made a study of the average incomes for five years, of the earnings of the University of Pennsylvania graduates in which it is shown that the owner of a business has the largest income, and this emphasizes an important truth that the individual who usually obtains the greatest wealth is the individual working for himself and not for another. Salesmen, printers and life insurance agents, rank next to the owners of business as to the amount of remuneration received each year, while chemists and engineers are well toward the bottom of the list, and are listed at about \$3000.00 per year. While there are no statistics on which we base any further deductions one is inclined to believe that as far as it applied to the metallurgical engineer, this amount is higher than the average pay received by technical graduates in this line. When one realizes the great responsibility and opportunity for service that is placed before the metallurgical profession there is no reason whatever, why the average income should not rank as high as that of any of the other worthwhile occupations.

An important responsibility rests on the members of this Society, the pioneers in the metallurgical industry, to so diligently devote themselves to their opportunities, to work so conscientiously in all of their undertakings, and then realize

that there is no law that forbids presentations to managers of important accomplishments in their department. All this then will have a tendency to increase the respect a manager should have for worthy calling and at the same time build up a higher standard of remuneration for work well done.

### THE STORY OF A STEEL TREATER

**T**HIS is the story of a steel treater, a true story, told to show how one of the many, just like you and I, was able to rise out of his mediocre surroundings and take enjoyment of that which we all seek—success.

A short few months ago this man was buried in a heat-treating room, carefully doing his daily work, at \$25.00 per. He was approached by one of our enthusiasts and asked to join the American Society for Steel Treating. Ten dollars looked big to him with the family needing things, and besides he had heard that these Steel Treaters were getting *high-brow* and that they spoke a peculiar language at their meetings, that they were "different." But, he was made of the right stuff, so he joined.

He had not paid so much attention to the "why" of his job but his first contact with the Steel Treaters showed him that they were discussing the "why" part of his own job. He then recalled that their talk sounded very much like conversations he had overheard at the plant between the superintendent and the metallurgist from the *lab*, and that frequently, after such talks, he was told to do things a little differently. Then it dawned upon him. If a fellow understood such things he would get the better jobs. His "big boss" was a level headed business man and surely there was common sense in the thing.

Then another thing came to him. Here at these very meetings were those same "high brows," even the metallurgist from the *lab*. They were quite human and very likeable and seemed to take an interest in him, along with the awakened interest in himself. He attended every meeting and read the TRANSACTIONS and entered into the spirit of the Steel Treaters in full swing and became well acquainted with the metallurgist from the *lab*. Then

came the opportunity, for which he had unconsciously prepared himself. His friend, the metallurgist, you see got around to different plants and "knew things." There was an opening at one of the company's branch plants. They were doing a big business in a quality product and were looking for someone to work with the men and show them how—but this man must understand his job, he must know the "why," or else they could not use him. The metallurgist at the *lab* got him the job.

Then comes the conclusion. The \$25.00 was doubled at once; instead of a job, he had a life's work; instead of routine work, he had diversity; instead of listening in, he was discussing things with the superintendent. Then he was given charge of the shop, and again his salary was raised. Now, he and his family, really know what it means to "get along" in the world, to have the association of fellow Steel Treaters and the value of finding out the "why." He also knows that he is made of the right stuff and that success really comes to those who are prepared for it. And he knows that the American Society for Steel Treating helped him prepare, gave him the start, and then placed Opportunity at his door, even as it can do for you and me.

S. L. H.

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### THE GEORGE SPOT

THE unique piece of research work performed by Harry S. George of the Union Carbide and Carbon Laboratories, Inc., described in detail in this issue of *TRANSACTIONS*, typifies the inventive genius of our American metallurgists, chemists, and engineers.

Through the simple application of an opaque disk properly placed in the optical system of an ordinary bench-type metallographic microscope, Mr. George has made it possible to more minutely and accurately study the microscopic structure of metals, their grain boundaries and physical condition, in their true relationship to the actual condition of the object.

While this development seems a simple one and one which should have been discovered long ago, nevertheless it required much study and concentration on the part of the author. It

shows that he had that fundamental knowledge of the properties of light and lenses which, of course, would be indispensable in a research of this nature. Knowledge of the fundamentals involved in the study of any problem is of absolute importance, otherwise the investigator simply stumbles along in the dark and seldom arrives at any definite goal.

Mr. George's "spot" will undoubtedly aid many investigators in their researches on the theory and constitution of metallic alloys and the result of the use of this method may cause several changes in the theories which have thus far been advanced.

Through the use of conical illumination the work of the metallographist will become somewhat more pleasant since it is considerably more interesting and less fatiguing to view objects in their three dimensions rather than in only two dimensions, such as is the case in ordinary vertical illumination. Nonmetallic inclusions, grain boundaries, slip planes, etc., can now be studied from a somewhat different point of view, which should result in some worthy researches on this phase of metallurgy.

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### ON TO PITTSBURGH

**W**HEN keen minds get together, as they will in Pittsburgh during the second week in October, it behooves all of the members of the A. S. S. T. to make plans immediately to be present at the conferences during the Annual Convention of the Society. The Annual Convention and Exposition are looked forward to, as making epochs in the progress of the association, and in the advancement of the arts and sciences connected with the manufacturer or treatment of metals.

The 1500 members of the Society who attended the conference last year, at Detroit, will need no special urging or inducement to impress them with the great importance and vast amount of valuable information that is to be obtained by attending a convention. It is only to those individuals who have never attended an annual A. S. S. T. get-together that there is need to have brought home very forcibly the great loss that will result to them in not having attended.

In speaking of the Convention last year, the *Iron Age* reported:

"An unqualified success was the general verdict of those who attended the fourth annual Convention and Exposition of the A. S. S. T. The record made by this Society, only three years old, both in technical papers and in exhibits, insures it a place among the leading technical organizations in the country and stamps its annual meeting as one to be looked forward to and to be reckoned with."

*The Iron Trade Review* stated:

"Probably the widest representation of the iron and steel industry ever witnessed in this country was assembled at the fourth annual Convention and Exposition of the A. S. S. T."

*Chemical and Metallurgical Engineering* said:

"Steel Treaters have done something which is perhaps unparalleled in the history of American technical societies. They have held a National Convention at which 40 per cent of their entire members enrolled was present. They were rewarded by the best meeting and exposition the A. S. S. T. has ever had."

The chairman of the meetings and papers committee has arranged in co-operation with the other members of the committee a program of papers, round tables and symposiums so that this session will mark a great advancement in metallurgical knowledge. While it is true that all the papers and discussions will be printed in the *TRANSACTIONS*, nevertheless the advantage of hearing them presented by the author, of being able to participate in the discussion and to ask questions upon points that do not present themselves at the time with sufficient clearness, all combined to make hearing a paper more valuable than reading it.

The hearing of papers read and discussed, is one of the important advantages to be obtained by attendance, yet the fact that you are brought into personal contact with the leading metallurgists and manufacturing executives of the coun-

try, is of importance. The opportunity to meet them and discuss with them your problems adds to the wonderful advantages to be obtained.

It is needless to call especial attention to the great educational value of the exhibits. There will be gathered together at Motor Square Gardens during the week of October 8th to 12th, the most imposing number of leading experts in the manufacturing of metals, metal-working machinery, supplies and appliances for metal treatment it will ever be possible for you to meet and talk with during the year.

When you consider that any problem you may have could quite easily be solved by conference with any one of these highly specialized individuals, and that you have hundreds with whom you may discuss your needs, you should not hesitate a moment in making your preparations to attend the Convention and Exposition.

Thousands are availing themselves of this opportunity presented annually by your Society and it is incumbent upon you to realize that that which is of benefit to others would certainly be of great value to you. If you have not as yet presented the subject of your attendance at Pittsburgh to the executive in the plant, it is time now to present the benefit that is to be obtained by attending the Convention and Exposition. Not only secure permission for your own attendance but bring the plant executives with you.

Again the railroads of the country have granted fare and a half for the round trip, and certificates entitling members and their families to this reduction will be mailed from the Society's headquarters about the first of September. Members of the Society can write to headquarters and secure certificates for individuals who plan to come to Pittsburgh to participate in the activities of the week.

While the social side of the Convention has not been emphasized, you may depend upon it that the previous reputation for highly enjoyable occasions will be continued at Pittsburgh. The various committees under the leadership of J. Trautman Jr., are exerting themselves to the highest degree of endeavor, in order that those who attend will not only enjoy the technical and inspirational side of the convention,

but will carry back home with them the idea that Pittsburgh has a real friendly and hospitable spirit. Not only have they made extensive preparations for the entertainment of the members and guests of the Society, but they have also made interesting plans for the entertainments of the ladies.

It is really important that you should begin your plans at once and make your hotel reservations from the list published in this issue of the *TRANSACTIONS*. As a member you should extend a cordial invitation to attend to all individuals, whom you feel would in any way profit by the Convention and Exposition.

### HOTEL RESERVATIONS FOR THE CONVENTION

In order that our members and guests may be well taken care of during the time of the annual convention in Pittsburgh, October 8 to 12 inclusive, we are again publishing the list of the hotels at Pittsburgh so that you may make your reservations immediately and thus be sure of accommodations.

In writing to the hotel please state the price and kind of room you wish, and request them to acknowledge your communication confirming the reservation and price.

In case you have difficulty in securing the accommodations you wish, a communication addressed to the chairman of the hotels committee, R. E. Polk, chief industrial engineer, Equitable Gas Co., Pittsburgh, Pa., will receive prompt attention.

#### List of Pittsburgh Hotels

##### William Penn

(Headquarters)

375	Rooms	with	bath,	2	persons,	Rate	\$3.50-5.00	each
375	Rooms	with	bath,	1	person,	Rate	4.00-8.00	

##### Fort Pitt

190	Rooms	with	bath,	2	persons,	Rate	\$2.50-5.00	each
100	Rooms	without	bath,	2	persons,	Rate	2.50	each
190	Rooms	with	bath,	1	person,	Rate	3.50-9.00	
100	Rooms	without	bath,	1	person,	Rate	3.00	

##### Hotel Henry

12	Rooms	with	bath,	4	persons,	Rate	\$2.50	each
12	Rooms	with	bath,	2	persons,	Rate	3.00	each
24	Rooms	with	bath,	1	person,	Rate	4.00	up



WILLIAM PENN HOTEL  
Convention Headquarters

#### Anderson Hotel

20	Rooms with bath, 4 persons,	Rate \$2.50	each
24	Rooms without bath, 4 persons,	Rate 2.00	each
10	Rooms without bath, 2 persons,	Rate 2.50	each
20	Rooms without bath, 1 person,	Rate 3.00	

#### General Forbes

17	Rooms with bath, 4 persons,	Rate \$2.00	each
9	Rooms with bath, 2 persons,	Rate 3.00	each
24	Rooms without bath, 2 persons,	Rate 1.50	each
25	Rooms with bath, 1 person,	Rate 4.00	up

#### Seventh Avenue Hotel

14	Rooms with bath, 4 persons,	Rate \$2.50-3.00	each
10	Rooms with bath, 2 persons,	Rate 2.50-3.00	each
20	Rooms without bath, 2 persons,	Rate 2.00-2.50	each

**Pittsburgh Natatorium**

(For gentlemen only)

175 Rooms, with swimming pool, cots, 1 person, Rate \$2.00

**Monongahela House**

10	Rooms with bath, 2 persons,	Rate \$3.00	each
40	Rooms without bath, 2 persons,	Rate 2.00	each

**Schenley Hotel**

5	Rooms with bath, 4 persons,	Rate \$3.00	each
10	Rooms with bath, 2 persons,	Rate 4.00	each
10	Rooms without bath, 2 persons,	Rate 3.00	each
10	Rooms with bath, 1 person,	Rate 7.00	
10	Rooms without bath, 1 person,	Rate 4.00	

**Rittenhouse Hotel**

25	Rooms with bath, 2 persons,	Rate \$2.00-3.00	each
20	Rooms with bath, 1 person,	Rate 3.00-4.00	

**Y. M. C. A., East Liberty**

10 Rooms without bath, 1 person, Rate \$2.00

**Negri Hotel**

25 Rooms with bath, 1 person, Rate \$3.00

**New Sixth Avenue**

15	Rooms with bath, 2 persons,	Rate \$3.00-4.00	each
15	Rooms without bath, 2 persons,	Rate 2.50-3.00	each
10	Rooms with bath, 1 person,	Rate 3.00	
5	Rooms without bath, 1 person,	Rate 2.00-3.00	

**Chatham Hotel**

5	Rooms with bath, 4 persons,	Rate \$2.00	each
20	Rooms with bath, 2 persons,	Rate 3.00-5.00	each
20	Rooms without bath, 2 persons,	Rate 2.50-3.00	each
15	Rooms with bath, 1 person,	Rate 3.00	

**MEMBERSHIP AND ATTENDANCE CONTEST**

**T**HE Membership and Attendance Contest that has been in action during the past year, came to a close on June 30 with the following results:

First Prize .....	\$200.00	Tri City .....	127.6 %
Second Prize .....	150.00	South Bend .....	99.3 %
Third Prize .....	100.00	New Haven .....	85.8 %
Fourth Prize .....	50.00	Cincinnati .....	65.5 %

The nearest to Cincinnati was North West with 56.4 per cent and Syracuse with 55.5 per cent. The standing of the other chapters in the contest was as follows:

Per Cent	Per Cent	Per Cent
5. North West .. 56.4	9. Hartford ... 49.5	13. New York .. 31.7
6. Syracuse .... 55.5	10. Providence .. 47.9	14. Washington .. 26.2
7. Detroit ..... 52.8	11. Milwaukee .. 38.8	15. Cleveland ... 25.7
8. Philadelphia .. 49.6	12. Rockford ... 38.6	16. Springfield ... 25.4
	17. Pittsburgh ... 18.9	

It is quite evident from the number of chapters participating in the contest that it has been very interesting and helpful, however, as the contest progressed it was observed that the smaller chapters had a certain advantage over the larger chapters, inasmuch as it required a smaller number, not only of new members but of those in attendance at meetings, to give a higher percentage.

While in actual figures Detroit has had the largest number of new members added to its roll nevertheless it had a low per cent of increase due to the fact that its increase was based on a larger original number. However, no credit is to be removed from those chapters that have so strenuously persevered to the goal throughout the entire year.

It is interesting to note that the progress of the Tri City and South Bend chapters has not been spasmodic but has been consistent throughout the year, and while with New Haven and Cincinnati the growth has been more or less steady, nevertheless both of these chapters sprang into prominence and high position toward the close of the contest by means of special activities on the part of individuals of their chapter and their membership committees.

## THE ANNEALING OF SHEET STEEL

By Francis G. White

*Abstract*

*In this paper the annealing of low-carbon sheet steel is discussed from the mill standpoint, and grain growth caused by a slow cooling rate from the annealing temperature is shown in photomicrographs. The complexity of sheet steel annealing will be realized when it is recalled that at times as many as 40 tons of sheets are placed in one furnace. The heat must be driven through an annealing cover and a blanket of air or gas surrounding the sheets, and then equally distributed throughout a mass of steel, probably three or four feet thick. While at this temperature as much air as possible must be excluded and the material cannot be exposed to the air until it is cool, otherwise, severe scaling of the sheets results. Slow cooling from this temperature is ideal for grain growth. If the sheets were heated to the upper critical range it would be impossible to open them because of "sticking," even though the cooling time could be shortened. Various furnace designs, temperature curves, and stamping tests are included in the paper and an outline of the general practice in one plant is discussed.*

## INTRODUCTION

GENERALLY speaking the requisites necessary for the successful annealing of sheet steel are, minimum grain growth, the removal of rolling strains, ease of opening after annealing, and a clear surface on the sheet. The cost of obtaining these qualities must of course be no higher than the trade will stand. To the user of sheet metal for stampings, the annealing is very important. While tin plate is not ordinarily thought of as a stamping steel, tin cans require double seaming, while

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A paper to be presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, Francis G. White, is metallurgical engineer with the National Enameling and Stamping Co., Granite City Steel Works branch, Granite City, Illinois. Written discussion of this paper is invited.

the tops and bottoms are light stampings. Galvanized sheets are very seldom stamped except when tite coated, but the trade seems to require a soft sheet whether it is blue, black, galvanized or tinned.

The various types of annealing furnaces, fuels, and methods of handling sheets and boxes are discussed. Certain annealing tests conducted by the author involving furnace design, fuels, etc., are incorporated in the text of this paper.

### BOX ANNEALING FURNACES

The fuels used may be either oil, gas, coal or electricity, while the furnace type may be the box, continuous box, or the continuous muffle. A furnace is usually built for one certain fuel, but probably with some rearrangement it could be adapted to more than one. The newer continuous box type furnaces are more or less in the experimental stage although numerous installations are giving great success. The old box types are the more common and are fired by either oil, gas, or coal. The first two of these fuels have a tendency to burn the sheets rather than anneal them, and the number of stickers is quite liable to be more pronounced. Two types of box furnaces are shown in Figs. 1 and 2, and after a trial on oil and gas were finally fired with coal screenings through automatic stokers, with fairly good success. Fig. 1, is a side-fired furnace while Fig. 2, is rear-fired. The problem of heat distribution within these furnaces had to be carefully studied before any set annealing practice could be followed. Sliding dampers on the flues, flues of various sizes, the height of the bridge wall varied, a recuperative bridge built, and the benches redesigned to allow the circulation of draft below the box, were some of the variables encountered.

Most of the tests described in this paper were run using one certain sized bottom and cover as shown in Fig. 3, with four making the weight of sheets in each box vary from 10,000 to as high as the cover would allow, this being about 42 inches,

such boxes charged into each furnace.  
16,000 pounds, depending of course on the size of the sheets. In the furnaces described, it was customary to pile the sheets

On first thought it would appear that a uniform temperature throughout the furnace would be ideal, but when it comes to annealing many different sizes of sheets, a nonuniformity is at times

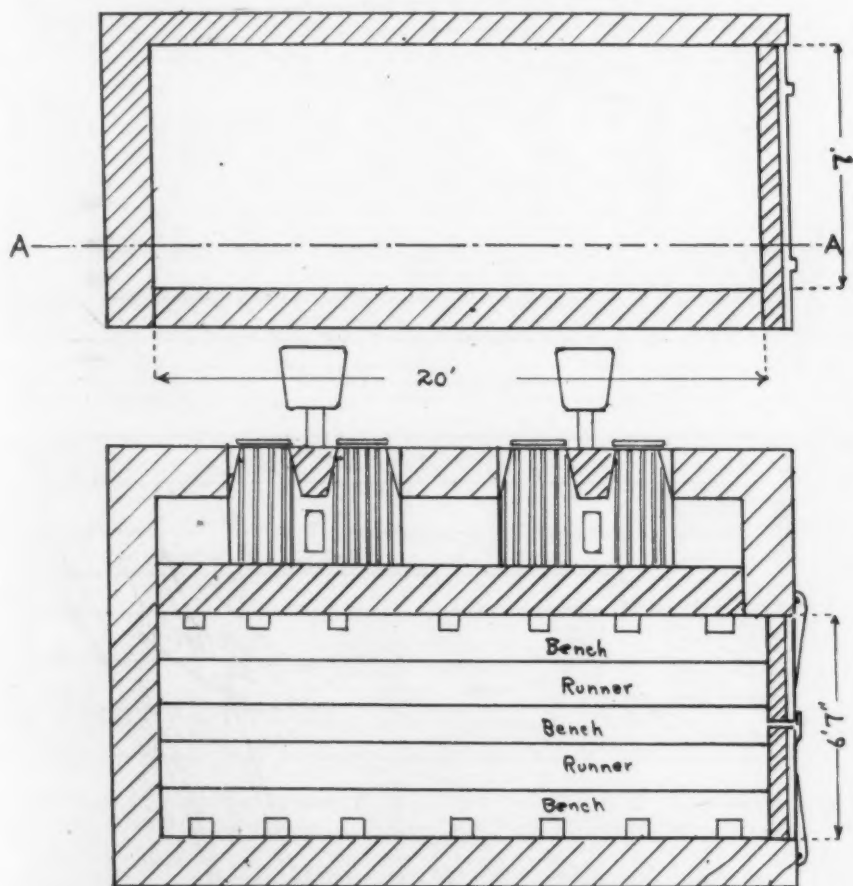


Fig. 1—Side-fired Double Stoker Box Type Annealing Furnace. Lower Sketch is Section AA Showing Flues. Upper Sketch Half Longitudinal Section.

advantageous because a heavy box of large sheets could be placed in the hottest portion of the furnace and the lighter boxes nearer the door. The actual practice, involving temperature and time will be discussed later in this paper under the heading of the various grades of steel, such as tin plate, deep stamping metal, etc.

Pyrometric equipment was installed, two thermocouples in the side-fired furnaces and one in the rear-fired. Rare metal

couples were used and an indicating instrument for the operator with recording instruments in the superintendent's office were supplied. It must be remembered that these instruments merely give the roof temperature of the gases and not the temperature

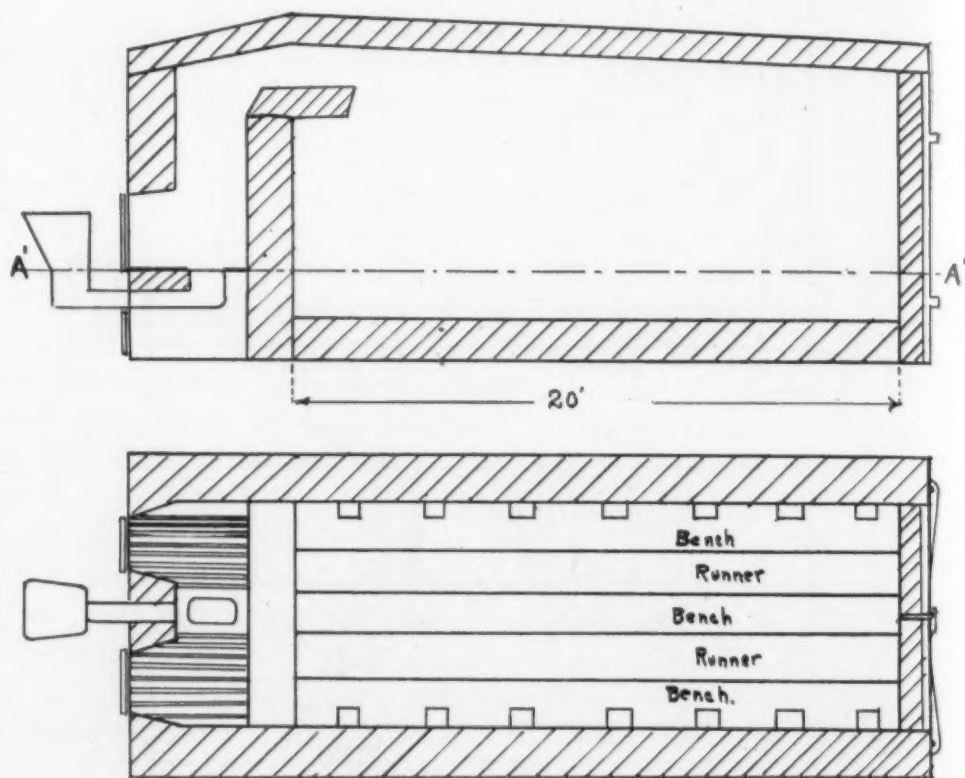


Fig. 2—Rear-fired Single Stoker Box Type Annealing Furnace. Lower Sketch is Section A-A', Showing Flues. Upper Sketch Half Longitudinal Section.

of the steel within the box. The relation of the temperature of the steel to the roof temperature was carefully determined on several hundred boxes. In this annealing, the time element was found to be an important factor to be considered, because the air space within the cover is a very poor conductor of heat. To obtain the actual temperatures within the boxes by pyrometers requires quite an added expense on routine work so that when a set practice was adopted this equipment was no longer used. By observing the roof temperature reading, and applying the time factor, a fairly accurate figure for the temperature within the box could be estimated. Fig. 4 shows the arrangement of the thermocouples as they were set within the boxes. Iron con-

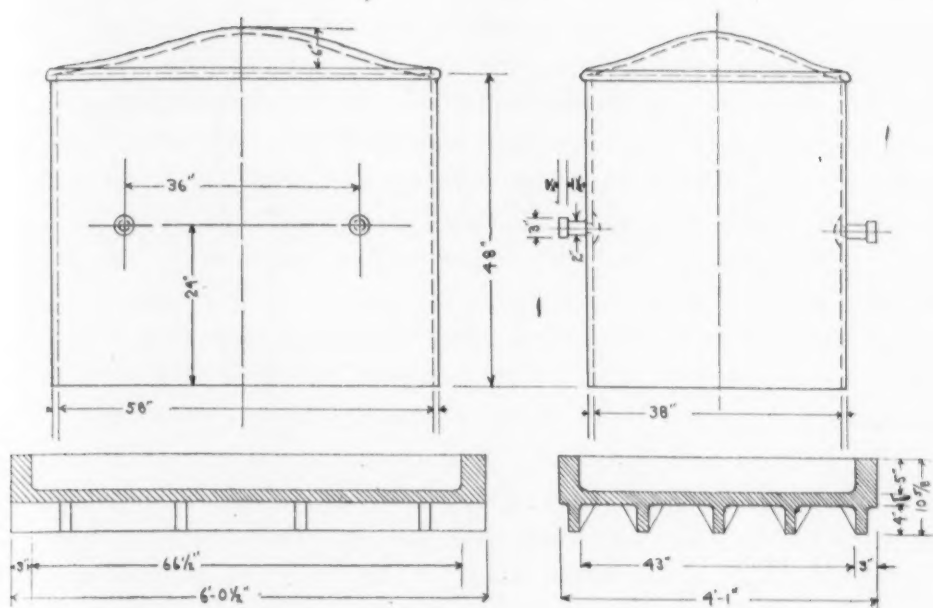


Fig. 3—Small Size Annealing Cover and Bottom Cover Weight—3300 Pounds.  
Bottom Weight—3250 Pounds.

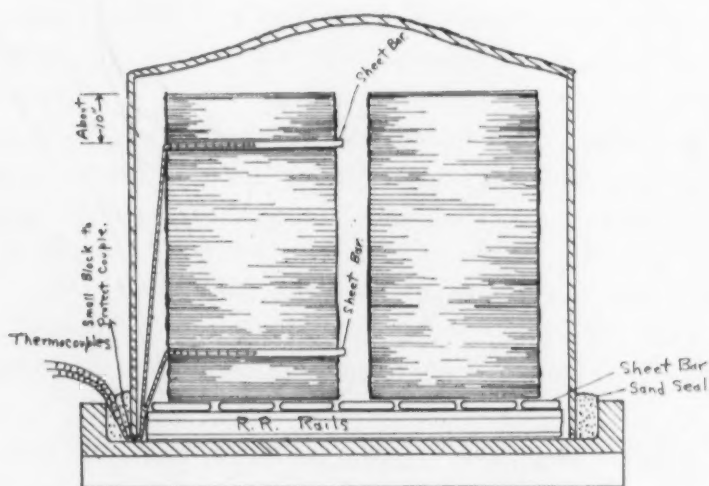


Fig. 4—Cross Section of Annealing Box Showing Method and Position of Inserting Thermocouples.

stantan couples were made up, each wire being covered with clay insulators, and the temperatures read with a potentiometer type pyrometer. The longest couples were about thirty feet, being used on the back boxes, while the others were shorter. In packing the sheets two  $\frac{5}{8}$ -inch sheet bars were placed in the pile one or two inches apart, the bottom ones about ten inches from the

bottom and the top ones a similar distance from the top. By inserting the couple so that the junction was in the middle of the pile, then leading the couple under the cover and piling sand around the bottom, an air seal was effected. The boxes were then run into the furnace and the couples were lead out under the door, where they were connected to a multiple point switch, so that the reading time was quite rapid. Ordinarily, the reading was stopped when the temperature on all couples began to fall, which was often several hours after the boxes had been removed from the furnace. These thermocouples rarely lasted over five heats, so for regular practice the expense was far too great.

On several occasions there was a decided rise in the temperature readings several hours after the boxes had been removed from the furnace and at a time when the temperature curve showed a uniform drop for several hours. This may be a new critical range and always occurred around 900 degrees Fahr. No further discussion of this peculiar action will be taken up in this paper, because the author has not enough data at hand to say much about it. This condition may look like a pyrometric misreading, as there seemed no justified cause for it. While speaking of temperature readings it might be well to say, that in all this work the cold end was compensated by junction boxes in small wells surrounded by circulating water under a constant temperature of 75 degrees Fahr., and for roof temperature work rare metal couples were used. While pyrometers, without a doubt, are very helpful to both the annealer and the superintendent, who can thereby check his work, there is nothing more harmful to "the man at the fire" than an inaccurate or unreliable instrument.

#### FURNACE CHARGING METHODS

Concerning the methods of charging box annealing furnaces, two types might be considered. The cannon ball type, where the bottom is placed on several iron balls of about eight inches in diameter, has a great advantage, inasmuch as it allows a greater circulation of heat around or beneath the box. This method, however, makes charging much more difficult and is quite liable to warp the bottoms of the boxes. When benches are used, the boxes are placed on a jack or charging machine and pulled or

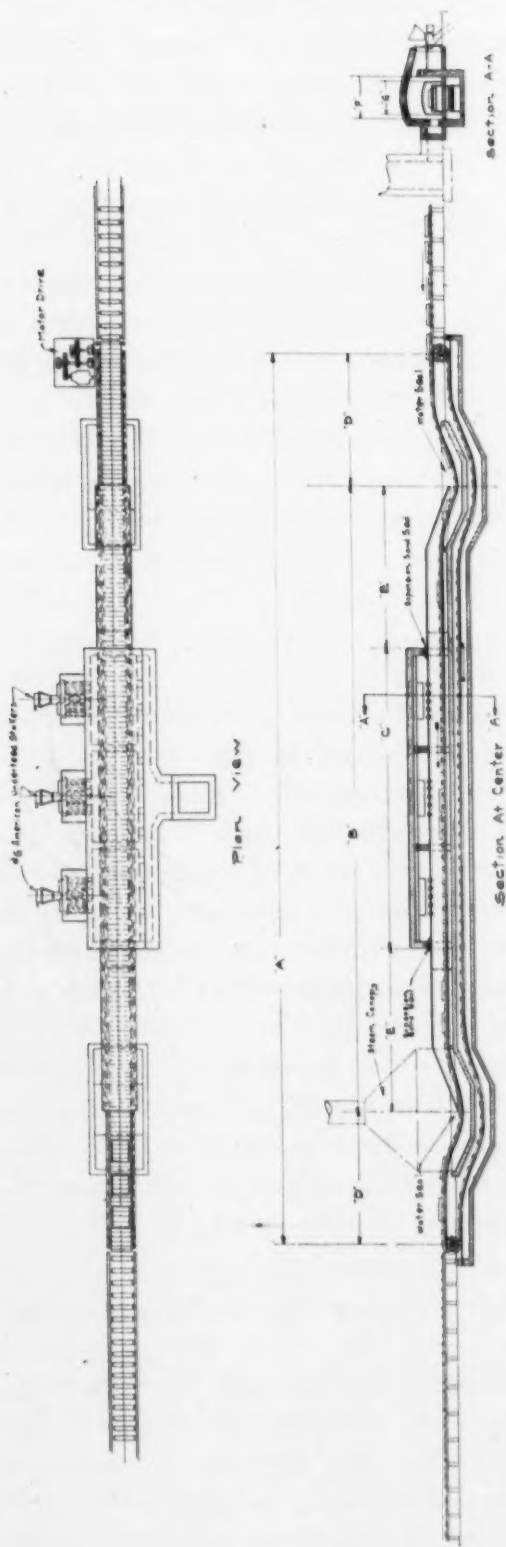


Fig. 5—Continuous Muffle Annealing Furnace for Sheet Steel Annealing. This Furnace Would Eliminate the Heating of Bottoms and Covers of Boxes.

pushed into the furnace. Here the bottoms are supported in many places and warping is less common. The bottoms are cast with fins which allow some circulation beneath them.

#### CONTINUOUS BOX-ANNEALING FURNACE

Undoubtedly the continuous furnace has some advantages over the stationary type, but there is still the necessity of expending a great deal of heat in heating the cover and bottom. At times this dead weight may exceed the weight of the sheets themselves. In this type of furnace the box is placed on a continuous belt or chain and carried through the furnace. By varying the speed of the chain a somewhat better control of heat is obtained over the stationary type of furnace.

#### CONTINUOUS ANNEALING IN MUFFLE WITHOUT BOXES

While the author does not know of anyone using a continuous muffle furnace, without the use of covers or boxes, and in which is maintained a reducing atmosphere, nevertheless such a furnace has many commercial possibilities. Fig. 5 shows the plan and elevation of such a furnace. It would eliminate the heating of bottoms and covers and except for the continuous chain and the furnace losses, all the heat expended would go directly into the material to be annealed. The sheets could be piled a few inches high, instead of forty or fifty as is common, thereby enabling the material to pass through the heating zone rapidly, cooling much more rapidly, and cutting the annealing time from approximately sixteen hours to an hour or two, or perhaps less. The temperature at which the sheets would stick could be obtained and then the furnace temperature not allowed to run over it.

#### STAMPING QUALITIES OF SHEETS

In box work, it is quite necessary to have an air-tight cover inasmuch as a leaky one will produce red or black sheets, burnt edges, or dirty surface. Lifting a cover too soon will give somewhat the same effect, and numerous customers believe that a sheet with well blued edges is a sign that it has been well annealed, while

in reality every box of steel could have a blue edge if it were allowed to get the air too soon.

Steel sheets are frequently deoxidized in annealing, i. e., annealed in a box in which the entrapped air is displaced by a nonoxidizing gas—and the resulting sheets are silvery white, with no trace of scale on them. Such a furnace as described would merely make the muffle an annealing cover, and since the cover method will work satisfactorily, the installation of a conveyer in a muffle is only a matter of mechanical arrangement. The blue annealing in an open furnace is a good example of rapid annealing, and on tests on similar gage box-annealed, the blue annealed sheets were much softer and stamped better.

Before taking up the furnace curves and actual temperatures used in these tests, the stamping qualities of sheets will be considered. While softness is usually the quality referred to, it seems an inaccurate way of expressing the stamping qualities, for an over-annealed sheet, exhibiting a large grain structure, will be dead soft if tested with any type of hardness tester, and a rough sheet will usually test softer than a highly polished one. The Erichsen testing machine, which seems to be the adopted standard for stamping tests, will show the stamping qualities quite clearly. In operation this machine holds a strip or square of about three inches in width, tightly against a die which has a circular opening in it which is approximately one inch in diameter. A rounded plunger on a screw is tightened up against the sheet and when a crack appears, the depth of impression is read on a gage. The relation of the sheet thickness and the depth of impression can be compared to a standard curve and expressed in percentage of the standard.

If we cut a diagonal across a sheet and take five or seven readings across this diagonal, and then find that the highest readings are near the edges, then we can say that the sheet is under-annealed, because the heat has not had time to penetrate to the middle of the pack. If the middle test gives the highest reading and the edges are low, then the edges have been at a high temperature for a sufficient length of time to allow grain growth. Photomicrographs have shown this to be true.

Dirty sheets, or those with a red surface or edges, have often been referred to as under-annealed, because in the stamping

operations the breakage runs high. Erichsen tests on such stock usually run up to standard because the machine runs quite lowly and friction is low. In rapid stampings, this scale acts as an abrasive on the dies and in turn tears the metal. Therefore, the surface condition is very important. A polished or cold rolled sheet will stamp better than a simple pickled and annealed one. Because of the strains set up, cold rolled material is usually re-annealed, but even then the grain structure is poor, and the added stamping qualities certainly relate to the surface. The exact ratio of these two factors is not known, but the fact that they are important seems quite evident.

#### CHEMICAL COMPOSITION OF SHEETS

The chemical composition of the steel has purposely been avoided up until this time. This paper considers only a low carbon open-hearth steel of about 0.10 per cent carbon, about 0.035 per cent sulphur, about 0.40 per cent manganese and phosphorus varying according to the purpose, use and gage of the sheet. Light gage, such as tin plate, will run around 0.080 per cent phosphorus while heavier gage may run as low as 0.005 per cent. Since practically all stampings are made cold, and phosphorus imparts cold-shortness to the steel, we may say that the lower the phosphorus, other things being equal, the better the steel for stamping, here again, there may be an exception in that low phosphorus will not give the surface to the finished sheet, and as has already been mentioned, the surface is very important. Also the very low carbon or iron sheets do not stamp as well. No study as to the reason for this has been made as yet.

#### LABORATORY STUDY OF ANNEALING

A steel having a carbon content about 0.10 per cent, would have a theoretical annealing temperature near 1620 degrees Fahr. If a pile of sheets were heated to this temperature it would require a hammer and wedge to get them apart. Then too, because of the large mass of material and the slow rate at which it cools, there is ample time for grain growth. Hence, a test was made as follows. Six sheets were chosen with no special attention given to their selection other than to secure a considerable

Table I  
Erichsen Tests  
Summary of Results

Test No.	T—Thickness of Sheet				D—Depth of Impression							
	Steel A		Steel B		Steel C		Steel D		Steel E		Steel F	
	18 Gage	D	18 Gage	D	20 Gage	D	22 Gage	D	27 Gage	D	30 Gage	D
1. Heated to 1100°F. cooled slowly	1.42	9.52	1.33	9.25	.90	8.48	.76	6.40	.43	6.00		
	1.39	9.30	1.33	9.58	.93	8.75	.77	6.61	.43	5.98		
	1.37	9.65	1.31	8.84	.93	8.62	.77	6.70	.44	4.90		
	1.37	9.58	1.33	9.32	.91	8.82	.79	6.68	.43	5.08		
	1.37	9.00	1.31	9.27	.92	8.70	.76	6.72	.43	5.15		
Average.....		9.41		9.25		8.67		6.62		5.42		
Heated to 1100°F. held for 18 hrs. cooled slowly	1.38	10.50	1.34	9.77	.95	9.00	.78	7.01	.43	7.20	.31	6.07
	1.39	10.35	1.33	9.90	.94	9.13	.79	6.97	.42	7.15	.30	5.38
	1.38	10.25	1.33	10.15	.95	9.14	.81	7.47	.43	6.85	.32	6.23
	1.38	10.24	1.30	9.80	.93	9.08	.79	7.36	.42	7.18	.29	5.72
	1.40	10.10	1.34	10.10	.92	9.05	.78	7.50	.42	7.40	.31	6.38
Average.....		10.29		9.94		9.08		7.26		7.16		5.96
3. Heated to 1200°F. cooled slowly	1.38	10.65	1.31	10.40	.93	9.23	.78	7.14	.43	7.25	.32	6.10
	1.35	10.15	1.32	9.85	.92	9.00	.79	7.75	.42	7.00	.32	5.90
	1.37	10.45	1.33	10.15	.93	8.92	.78	7.65	.43	6.97	.32	5.65
	1.36	10.28	1.32	9.80	.94	9.30	.78	7.66	.42	7.25	.32	6.98
	1.36	10.25	1.33	9.90	.95	9.00	.76	7.40	.43	6.50	.32	6.85
Average.....		10.35 +		10.02		9.09		7.52		6.99 +		6.30
4. Heated to 1200°F. held 16 hrs. cooled slowly	1.37	10.20	1.34	10.70	.93	9.18	.78	8.16	.42	7.53	.32	6.80
	1.40	10.68	1.28	10.40	.95	9.95	.76	7.80	.43	7.58	.31	6.94
	1.38	10.85	1.31	10.45	.92	9.52	.79	8.16	.42	7.41	.32	6.70
	1.37	10.50	1.31	10.40	.93	9.36	.79	7.95	.42	7.66	.32	7.05
	1.39	10.50	1.32	10.37	.92	9.25	.77	7.67	.43	7.93	.30	6.46
Average.....		10.54 +		10.46		9.45		7.95		7.62		6.79
5. Heated to 1300°F. cooled slowly	1.36	10.35	1.36	9.91	.96	9.27	.80	8.05	.43	7.32	.31	6.84
	1.37	10.05	1.32	10.27	.94	9.18	.79	8.10	.42	7.34	.31	6.53
	1.37	10.35	1.33	10.20	.92	9.45	.77	7.90	.42	7.00	.31	6.87
	1.38	10.60	1.32	10.27	.92	9.20	.80	8.22	.42	6.28	.31	6.23
	1.35	10.55	1.31	10.30	.94	9.52	.78	7.85	.43	7.57	.31	6.45
Average.....		10.38		10.19		9.32		8.02		7.10		6.58
Heated to 1300°F. held 16 hrs. cooled slowly	1.36	10.65	1.32	10.17	.95	9.15	.78	7.95	.42	7.23	.32	6.60
	1.36	10.46	1.29	10.34	.94	9.30	.79	8.25	.43	7.32	.32	6.32
	1.36	10.50	1.33	10.49	.93	9.45	.78	7.80	.43	6.67	.32	6.20
	1.37	10.44	1.33	10.07	.94	9.12	.77	8.48	.43	6.50	.31	6.52
	1.36	10.40	1.33	10.05	.94	9.42	.77	8.40	.43	7.75	.30	6.47
Average.....		10.49		10.22		9.29		8.18		7.09		6.42
7. Heated to 1400°F. cooled slowly	1.37	10.15	1.29	10.10	.94	9.25	.78	7.78	.43	7.23	.31	6.55
	1.38	10.04	1.33	10.10	.95	9.00	.78	7.38	.41	7.45	.31	6.40
	1.38	10.40	1.30	10.10	.91	8.99	.77	8.10	.43	7.05	.31	6.27
	1.38	10.40	1.31	9.60	.95	9.00	.79	7.50	.43	7.37	.31	6.84
	1.36	9.90	1.31	9.88	.94	8.70			.43	7.07	.31	6.40
Average.....		10.18		9.96		8.99		7.69		7.23		6.49
8. Heated to 1400°F. held 16 hrs. cooled slowly	1.37	10.47	1.33	10.65	.95	9.05	.78	8.95	.43	6.35	.29	6.10
	1.39	10.49	1.33	10.71	.94	9.20	.78	8.25	.43	7.50	.31	6.03
	1.37	10.55	1.32	10.35	.94	8.50	.77	7.80	.43	7.30	.29	6.41
	1.37	10.50	1.28	10.10	.93	8.66			.42	7.58	.31	6.20
	1.37	10.55	1.32	10.40	.92	9.10			.42	7.28	.31	6.30
Average.....		10.51		10.44		8.90		8.33		7.20		6.21
Erichsen Standard Deep Stamping Steel.....	1.37	10.74	1.32	10.63	.93	9.67	.78	9.28	.43	8.12		
Tin Plate Steel...									.43	7.65	.30	6.96

Analysis of Steel—Table I

Steel	C.	Mn.	Phos.	Sul.
A.....	.12	.38	.011	.037
B.....	.12	.34	.011	.042
C.....	.12	.31	.017	.047
D.....	.10	.28	.015	.049
E.....	.13	.25	.054	.037
F.....	.14	.25	.089	.054

range in gage. The sheets were cut into 3½-inch squares and the squares from each sheet thoroughly shuffled together and marked. Five squares were taken from each sheet for each experiment, and the sheets were prepared for annealing by packing in a small metal box and covered with clay and fine sand, special effort being made to exclude the air. The box was then placed in a small electric furnace and two annealings were made at each of the following temperatures: 1100, 1200, 1300 and 1400 degrees Fahr. The first run in each case consisted simply in bringing the furnace to the desired temperature, and then cooling it slowly. The second run in each case was conducted in the same manner except that when the desired temperature was reached it was maintained for a definite number of hours. The furnace was so regulated that the rise in temperature approximated 100 degrees Fahr. per hour, and the cooling at about 50 degrees Fahr. per hour. This heating and cooling rate is very similar to the rate inside an annealing cover. As the tests annealed were so small it can be assumed that the temperature within the electric furnace would equal the actual temperature of the samples annealed.

After annealing, the squares were tested on an Erichsen machine and the results tabulated as in Table 1. A graphical representation of the same is shown in Fig. 6. Photomicrographs of this test are shown in Figs. 7 to 14, the first three showing some rolling strains while the latter ones (annealed at 1300 degrees Fahr. or over) show grain growth. The Erichsen graph corroborates this and it seemed wise to carry on the experiment in the annealing room at 1200 to 1300 degrees Fahr. This temperature would give as good if not better results in stamping, and the sheets would open quite easily after annealing, since the lower temperature would be less harmful upon the furnace and

covers, and since there was a considerable saving of fuel, this new practice reduced annealing costs without deteriorating the product, in fact in many cases improving it.

#### MILL STUDY—CANNON BALL TYPE FURNACE

In order to further carry out this test the temperature was taken on ten heats, couples being placed inside the boxes, and

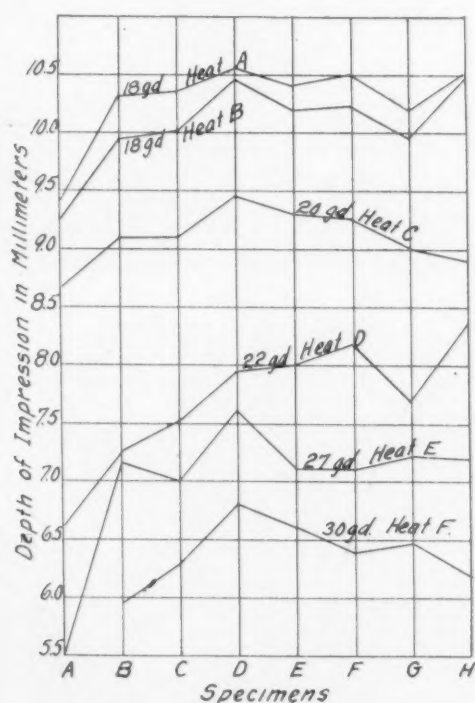


Fig. 6—Graphical Representation of Data of Table I. Specimen A, Heated to 1100 Degrees Fahr.; Specimen B, Heated to 1100 Degrees Fahr., Held for 16 Hours; Specimen C, Heated to 1200 Degrees Fahr.; Specimen D, Heated to 1200 Degrees Fahr., held for 16 Hours; Specimen E, Heated to 1300 Degrees Fahr.; Specimen F, Heated to 1300 Degrees Fahr., held for 16 Hours; Specimen G, Heated to 1400 Degrees Fahr.; Specimen H, Heated to 1400 Degrees Fahr., held for 16 Hours. All Specimens Cooled Slowly after Heating.

test sheets being taken out after annealing at a distance of one to two inches from the couple. The furnace curves on Test 7, Table II are shown in Fig. 15. The maximum and minimum temperature of the sheets on this particular heat is seen to be only 40 degrees Fahr. In the study on bench type furnaces, it will be seen that this variation runs up to 300 degrees Fahr. which makes it quite impossible to correctly anneal the whole

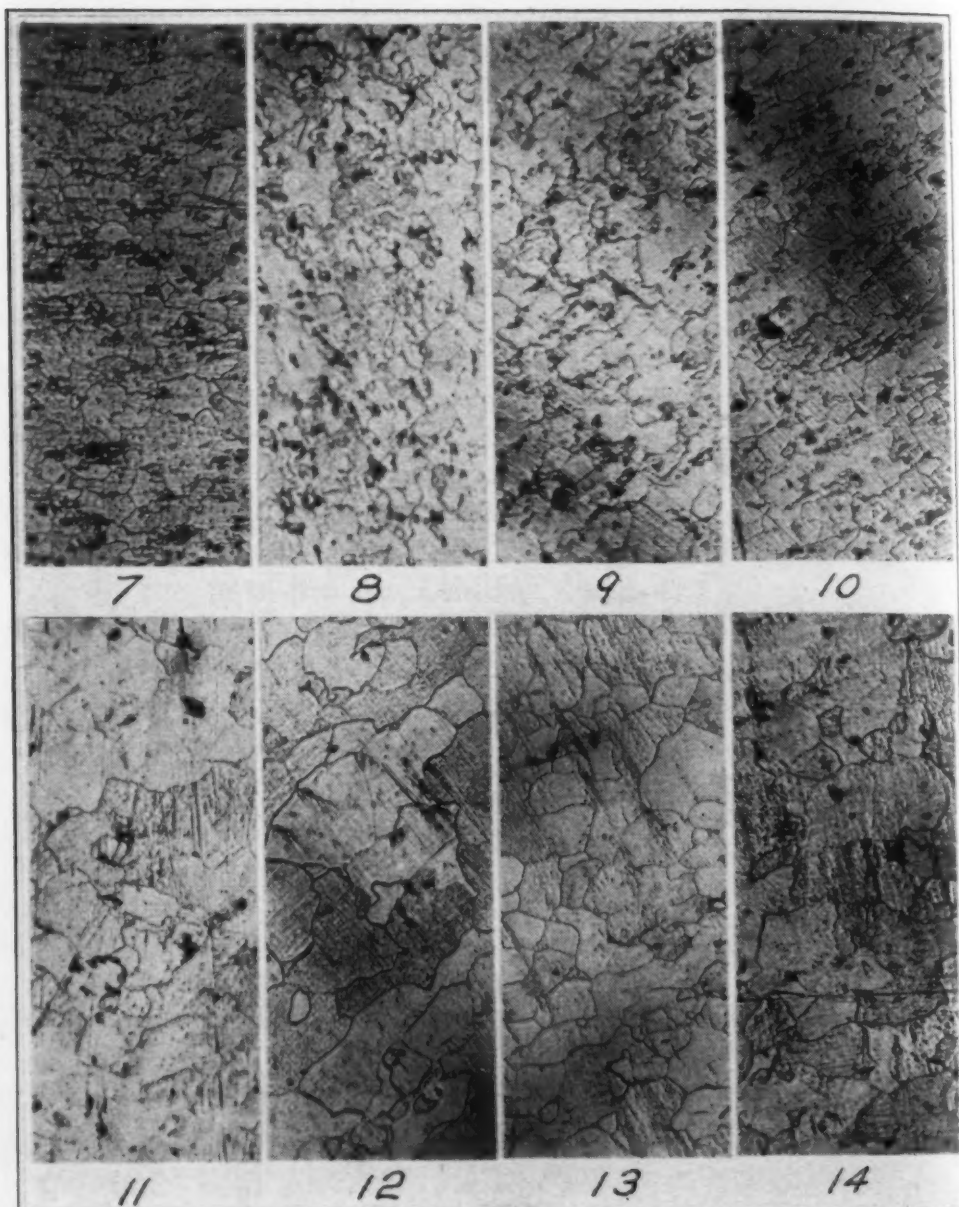


Fig. 7—Steel Heated Slowly to 1100 Degrees Fahr. Cooled slowly in Furnace. Fig. 8—Steel Heated Slowly to 1100 Degrees Fahr., Held at Temperature 18 Hours. Cooled Slowly in Furnace. Fig. 9—Steel Heated Slowly to 1200 Degrees Fahr. Cooled Slowly in Furnace. Fig. 10—Steel Heated Slowly to 1200 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Fig. 11—Steel Heated Slowly to 1300 Degrees Fahr. Cooled Slowly in Furnace. Fig. 12—Steel Heated Slowly to 1300 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Fig. 13—Steel Heated Slowly to 1400 Degrees Fahr. Cooled Slowly in Furnace. Fig. 14—Steel Heated Slowly to 1400 Degrees Fahr. Held at Temperature 16 Hours. Cooled Slowly in Furnace. Figs. 7-10 Show a Fairly Fine Grained Structure. Still Showing the Effect of Straining. Figs. 11-14 Show Well Formed but Large Grains. All Photomicrographs  $\times 100$ .

Table II  
Erichsen Test  
Cannon Ball Type Furnace

Test No.	Position of Sheet in Box	Thickness in m.m.	Depth of impression diagonally across sheet	Erichsen Test				Box Average	Roof average during firing Time	Hours fired	Hours soaked	Total Time in Furnace	Max. Temp. at couple	Tests higher on Center or Edge	
1.	A-Top	93	1000	1015	940	1000	1015	102.5	106.3	1834	13½	8	21½	1500	E
	C "	91	960		950		920	97.8					1450		
	E "	87	1000	1050	1090	1105	1070	111.7		Ave. Top—104.0%			1400	C	
	B-Bot.	92	1100	1010	1080	1100	1100	111.6		Ave. Bot.—109.8%			1390	E	
	D "	91	1046	1054	1080	1010	1010	108.0					1350	C	
2.	A-Top	60	1025	980	963	1004	980	113.4	113.4	....	12	6	18	1440	E
3.		91	1000	1020	1075	1055	1035	107.5	111.8	1934	10½	11	21½	1560	C
		90	1020		1156		1100	113.8							C
4.	A-Top	80	975	1100	1110	1140	1142	116.9	112.3	....	10½	11	21½	1470	
	C "	89	1055	1030	1060	1030	1015	108.5						1460	C
	B-Bot.	86	1110	1110	1147	1158	1080	118.0		Ave. Top—112.7%				1390	C
	D "	83	975	1060	1060	1025	1065	110.1		Ave. Bot—112.0%				1380	
	E "	79	990	1020	982	1025	1010	108.0						1360	E
5.	A-Top	80	1030	990	1010	975	974	106.7	109.3	1813	12	7	19	1480	
	C "	77	1040	1015	990	1050	995	110.0						1470	E
	E "	80	1065	1045	1053	1050	1070	113.1		Ave. Top—109.9%				1460	E
	B-Bot.	79	985	956	995	1020	1050	107.5		Ave. Bot—107.5%					
6.	A-Top	87	1043	1020	1080	1050	1050	110.1	113.7	1814	12½	2	14½	1380	C
	E-Top	81	1075	1065	930	1055	1070	113.8						1380	E
	B-Bot.	76	1020	1045	1030	1053	1080	113.3		Ave. Top—111.9%				1340	
	D "	80	1085	1115	1100	1140	1140	118.7		Ave. Bot—114.8%				1320	
	F "	80	1070	1065	1062	1000	1055	112.4						1310	
7.	A-Top	81	970	925	995	960	960	102.7	109.5	1945	10	11	21	1390	C
	C "	79	970	1050	1012	1052	1018	109.5						1380	C
	E "	75	1015	1000	1010	1000	1010	109.5		Ave. Top—107.2%				1380	
	B-Bot.	80	1055	1075	1015	1046	905	109.0		Ave. Bot—111.8%				1365	
	D "	78	1075	1000	1010	1031	1040	111.1						1360	E
	F "	77	1050	1085	1086	1046	1070	115.2						1350	C
8.	A-Top	80	975	965	965	950	970	103.3	107.5	1892	14	7½	21½	1475	E
	C "	77	1010	1028	1005	1025	1000	109.5						1460	
	E "	79	1042	1025	991	1005	1028	109.4		Ave. Top—107.4%				1450	E
	B-Bot.	80	923	975	985	982	995	104.0		Ave. Bot—107.6%				1395	
	D "	83	1000	1060	1000	1036	987	107.9						1390	
	F "	82	1060	1034	1060	1050	1000	110.7						1385	C
9.	A-Top	81	1040	1030	1066	1005	1120	112.3	114.2	1975	16	6	22	1425	C
	C "	62	1028	1035	1025	1005	1000	117.6						1410	C
	B-Bot.	65	1040	1030	1054	1040	980	115.6		Ave. Top—114.9%				1380	C
	D "	61	1030	1030	1041	1060	935	116.6		Ave. Bot—113.6%				1365	C
	E "	82	1020	1030	1057	1035	990	109.2						1350	C
10.	A-Top	78	985	980	970	985	1025	106.5	110.0	1850	8	8	16	1420	E
	C "	84	1140		1075		1060	115.5		Ave. Top—111.0%				1415	
	B-Bot.	86	1055	1070	962	1038	986	107.0		Ave. Bot—107.0%					E

AVERAGE FOR SHEETS—110.4%: FOR TOP SHEETS—109.7%: FOR BOTTOM SHEETS—111.0%.

12 edges ran higher than centers and 16 centers ran higher than edges.

Location of thermocouples shown in Fig. 17. Erichsen Standard for Stamping and Folding Sheets used.

charge. The material annealed in this test was 21 and 22-gage deep-stamping steel. It amounted to several hundred tons and was followed through the stamping operations. The breakage

was so low that it verified the Erichsen test readings. On Test I, Table II, the temperatures were taken for information only; thereafter the annealing was done as far as possible to conform with the laboratory practice. It will be noted in Fig. 15 that the temperature continues to rise within the box after the fire is cut off—because the steel absorbs quite a lot of heat from the furnace itself—and it took two or three heats before this rise could be estimated.

Test 3, Table II, produced quite a number of red sheets although the temperature was very high, showing that red sheets do not necessarily mean that the steel was under-annealed. The test taken as a whole showed over-annealing—at least as far as the temperature was concerned. The top sheets (which received more heat than the bottom ones) gave a slightly *lower* Erichsen value and the middle of all sheets as compared to the edges gave a *higher* value. This would seem like a very satisfactory check on the work. In Fig. 16 the furnace temperatures were plotted against the Erichsen percentage for each thermocouple, and clearly show a case of over-annealing. Table II is a record of all Erichsen tests, furnace temperatures, etc.

#### MILL STUDY—BENCH AND CHARGING MACHINE TYPE FURNACE

As mentioned earlier in this paper the temperature variation within the box is much greater in this type of furnace. In Fig. 17 the inside temperature is plotted against the roof temperature and a wide variation (300 degrees Fahr.) was recorded. This furnace was a side-fired one, with two fire boxes and the charge in all four annealing boxes was of equal weight and size. While the rear-fired, (one fire box-type) has even more unequal heat distribution, the boxes are arranged in such position as to compensate for this. Erichsen tests on this study were very similar (at equal temperatures) to those in the previous study.

#### HAND FIRED VERSUS STOKER FIRED FURNACES

It was thought that a considerable saving in coal could be made by firing these furnaces by hand in place of using a mechanical stoker. Numerous tests were run on two similarly built furnaces, differing only in the method of firing. It was found

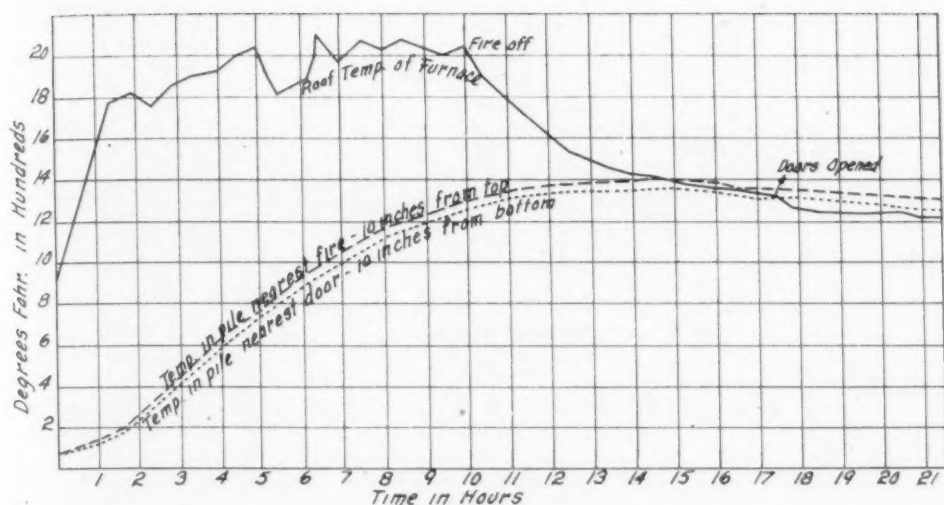


Fig. 15—Cannon Ball Type—Single Stoker Furnace Curves Show Roof Temperature of Furnace, Temperature in Pile Nearest Fire and 10 Inches from Bottom, Temperature in Pile Nearest Fire and 10 Inches from Top. Charge Contained 15 Tons of Sheets and 12 Tons of Annealing Box. Test 1, Table II.

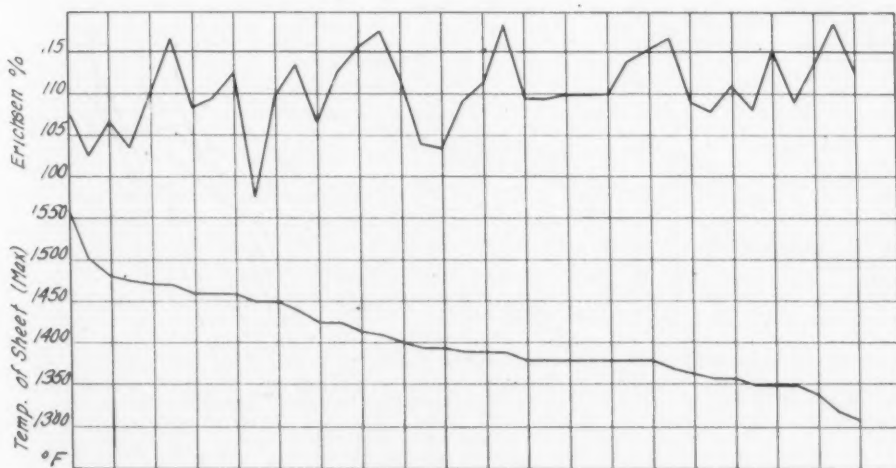


Fig. 16—Relation of Maximum Annealing Temperature to Stamping Qualities of Sheet Steel as Shown by the Erichsen Test. Material was Deep Stamping Steel Annealed in a Cannon Ball Furnace. Data from Table II.

difficult to get equal weights of similar size sheets, covers and bottoms. The nearest approach to this is shown in Fig. 18. It was also deemed necessary in order to obtain a fair test, to fire at equal temperatures an equal length of time. The stoker-fired furnace burned 3542 pounds of coal to anneal 46,030 pounds of sheets, while the hand-fired one burned 4195 pounds on

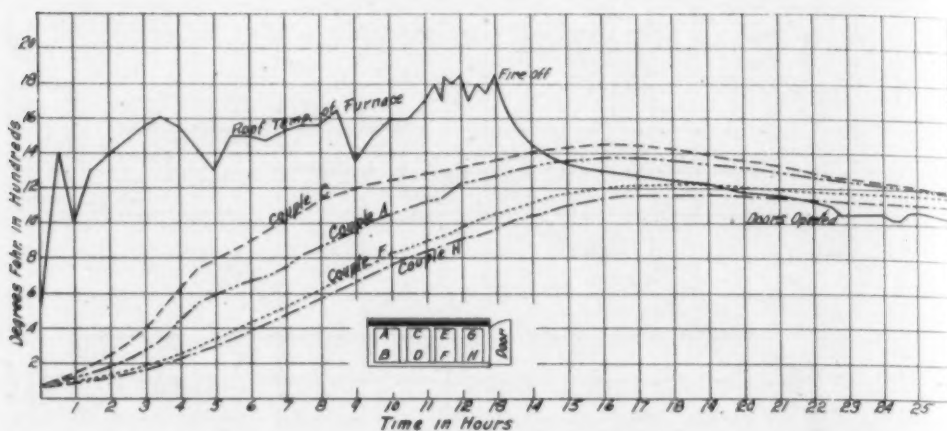


Fig. 17—Bench Type—Double Stoker—Side-Fired Furnace. Curves Show Roof Temperature of the Furnace, and the Temperature of the Boxes Within the Furnace. Position of Couples Shown in Sketch. Couples B, D, E and G Would Plot Between C and H Which are the Maximum and Minimum Temperatures of the Sheets. Data from Table II.

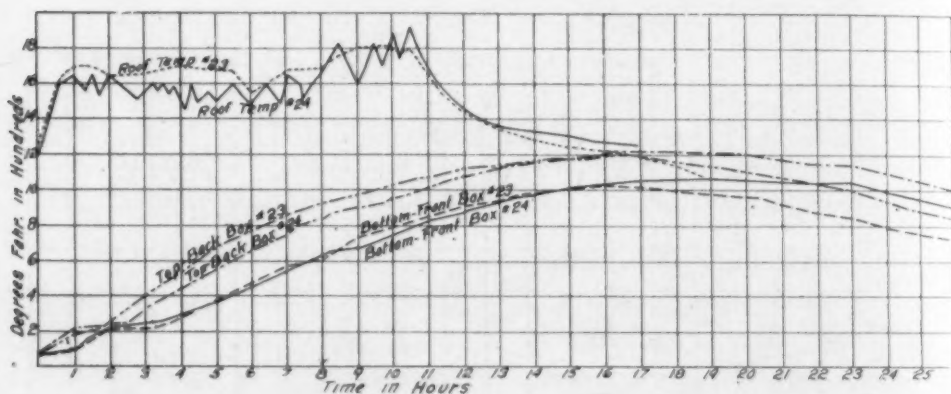


Fig. 18—Hand-Fired Versus Stoker-Fired Furnace, Showing the Results Obtained in a Test to Check the Relative Economy of Each Type of Furnace. An Average of All Tests Showed About an Equal Coal Consumption on Each Furnace with Labor Considerably Higher on the Hand-Fired Type.

52,755 pounds of metal. An average of all tests showed about an equal coal consumption with labor considerably higher on the hand-fired type, therefore, the use of stokers was continued.

#### GENERAL PRACTICE

The majority of light gage, annealed sheets are pickled in sulphuric acid; the solution averaging about 8 per cent by volume. If this operation is done after annealing, it is necessary to put the sheets through a dryer. If it is done before, the annealing

furnace is in reality the drier. If the sheets are allowed to dry before they are covered and placed in the furnace, it is difficult to clean them. Therefore, it is advisable to charge them into a hot furnace at a temperature around 1000 degrees Fahr. Slow firing would undoubtedly reduce the difference in temperature between the top and bottom sheets but it is perhaps more im-

Table III  
Temperature Differences During Firing

All Bench Type Furnaces except No. 2. Rear-Fired unless specified.

Test	Inside Temp. Degrees Fahr.		Average Roof Temp. during Firing	Temp. During Time in Fur- nace	Firing Time	Soak- ing Time	Hours in Fur- nace	Diff. in Temp. Rise Per Hour Degrees Fahr.		Furnace No.
1.	1450	1050	1542	1459	13	3	16	85	400	24 Side Fired
2.	1400	1360	1846	1722	10	5	15	94	40	7-Cannon Ball Type
3.	1400	1290	1748	1628	9	6	15	94	110	14
4.	1340	1250	1565	1526	10	4	14	96	90	13
5.	1340	1280	1590	1552	11	3	14	96	60	14
6.	1300	1180	1567	1525	11½	4½	16	81	120	23-Side Fired
7.	1280	1170	1630	1563	9	4	13	100	110	13
8.	1275	1115	1485	1469	18	3	21	58	160	13
9.	1250	1210	1446	1431	16	2	18	70	40	14
10.	1250	1190	1478	1453	10	3	13	96	60	14
11.	1230	1180	1480	1413	10	3	13	95	50	14
12.	1220	1190	1525	1483	15	3	18	68	30	10
13.	1220	1180	1490	1458	14	2	14	87	40	13
14.	1200	1040	1706	1540	6	4	10	120	160	24-Side Fired
15.	1200	1020	1658	1536	11½	4½	16	75	180	23-Side Fired
16.	1200	1060	1596	1517	11½	5½	17	70	140	24-Side Fired
Average-	1285	1173	1585	1517	11.3	3¾	15 2	87	112	

portant to be able to clear them. Data on sixteen heats are given in Table III. The average roof temperature during the firing time was 1590 degrees Fahr. and was obtained in an average of 11½ hours. The soaking period (which does not figure in this average) was about 4 hours, after which the doors of the annealing furnace were opened and the boxes allowed to cool for three or four hours before removing. This delay seemed necessary because of the extreme heat which would work an unnecessary hardship on the men. It has since been found advisable to set a maximum roof temperature of 1800 degrees Fahr., and by bringing the temperature up as rapidly as possible, the annealing time has not been lengthened. After removing from the furnace, the boxes are set on the floor to cool, and the covers are not raised for 30 hours.

Such material as tin plates or any full finish cold rolled

(Continued on Page 216)

## CONICAL ILLUMINATION IN METALLOGRAPHY

## A New Method of Illuminating Opaque Objects Obliquely

By Harry S. George

*Abstract*

*Conical illumination is a new method of lighting for microscopic examination and photomicrography of opaque objects. A more natural representation and clearer insight into structural relationships are its marked advantages. The present article describes and illustrates the method in its application to metallography at magnifications ranging from 100 to 4000 diameters.*

ABILITY to distinguish and interpret metal structures is fundamentally affected by the method of illumination. For the present purpose, it is hardly necessary to do more than recall that the methods heretofore in use are of two distinctly different kinds. The distinguishing difference is that while in one system, light is admitted to the object through the objective, returning upon itself through the objective and being suitably deflected to the observer; in the other system, light is thrown on the object from some point outside the objective and then is reflected through the objective to the eye. The first system is known as vertical or axial illumination and the second, as oblique illumination. These two methods have reached a stage of almost complete development and have become so familiar to metallurgists through long use, that anything radical in the way of improvement or modification will be greeted with at least a degree of curiosity or even doubt.

Metallurgists become so familiar with metal structures that they perhaps do not realize that the mental picture seldom coincides with the physical image in the microscope. The process of examination has become second nature and the observer is not always aware that he is not actually seeing physically all that

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A paper to be presented at the annual convention of the Society, Pittsburgh, October 8-12, 1923. The author, Harry S. George is associated with the Union Carbide and Research Laboratories, Inc., Long Island City, N. Y. Written discussion of this paper is invited.

he visualizes mentally. To take a simple illustration, a polishing scratch on a polished metallographic specimen appears under vertical illumination to be a black line on a bright surface. We interpret this to mean that a hard abrasive particle has plowed a furrow through a yielding metal even though the furrow is not seen. Again, a polygonal configuration of thin black lines on a bright surface is the outlined cross-section of grains of metal although few know the nature of these outlines, whether a grain boundary is a step down from one level to another, or a ditch etched out between grains, or a ridge. That which is seen through the microscope bears the same relationship to the structure that a mechanical drawing does to the object it represents. For example, when pearlite is examined under sufficiently high power, say 500 or 1000 diameters, the plates and globules of cementite ap-

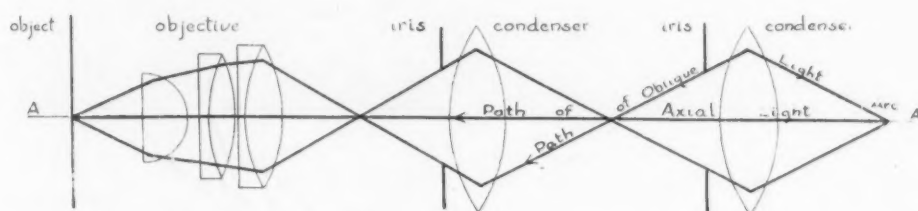


Fig. 1—Diagram of Path of Light in Metallographic Microscope, Using Vertical Illumination.

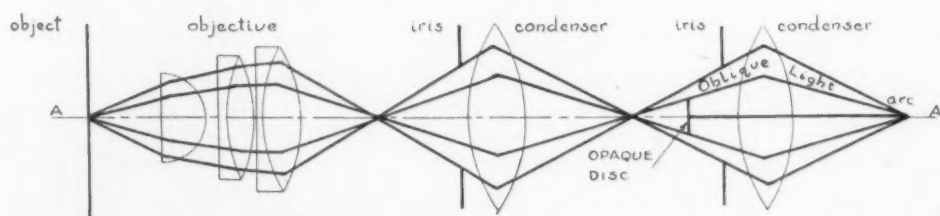


Fig. 2—Diagram of Path of Light in Metallographic Microscope Using Conical Illumination.

pear merely as outlined areas although their real condition is one of relief.

The reason why constituents are seen only in outline under vertical illumination is, of course, that they are illuminated by light parallel, or very nearly parallel, to the axis of the lens system, and as this light falls normally upon the surface of the ob-

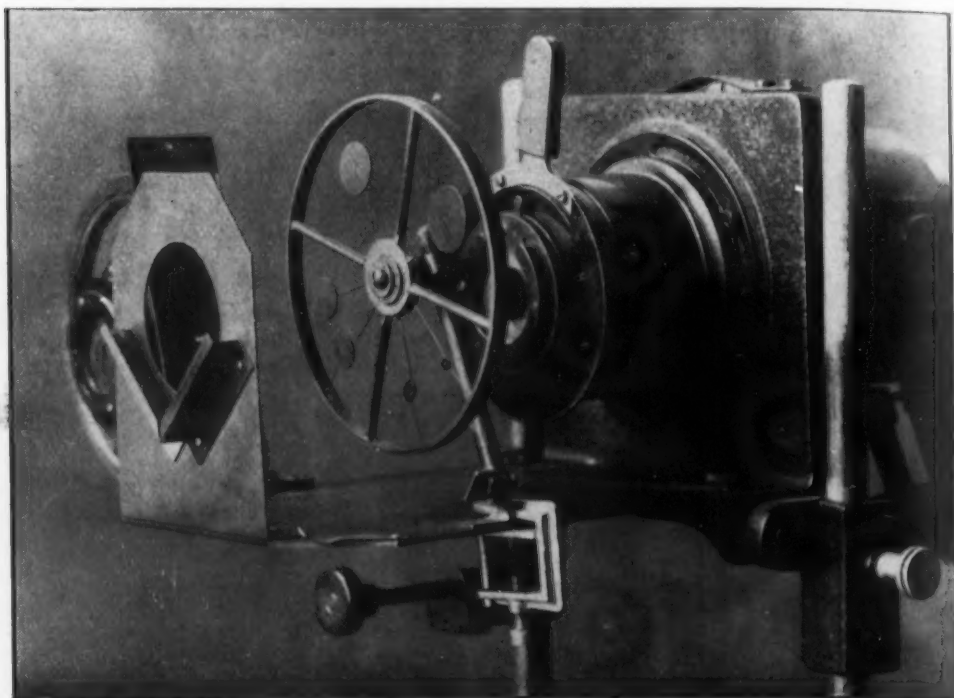


Fig. 3—Device for Obtaining Conical Illumination. The Discs are Mounted within a Wheel so that they may be Readily Adjusted in the Path of Light.

ject no shadows are cast and very little shading is manifest. This is an unnatural condition but has become so familiar as to seem natural. It results from the limitations imposed by the optical equipment, which necessitate, in the case of the higher magnifications, passing the illuminating beam of light through the lens system.

Even in the case of the lower powers where the working distance is sufficient to permit light to come to the object obliquely, the effect, while instructive in that it is open to interpretation, is nevertheless, subject to the criticism, owing to the extreme obliquity of the light, of being an unnatural representation. The contrast between the appearances of a structure viewed by the above mentioned systems of illumination is very striking and is too well known to need discussion.

It would be desirable, then, to view microscopic objects in a more natural way: to see them in relief, as one sees a man's facial characteristics. Furthermore, as the trend of practice seems

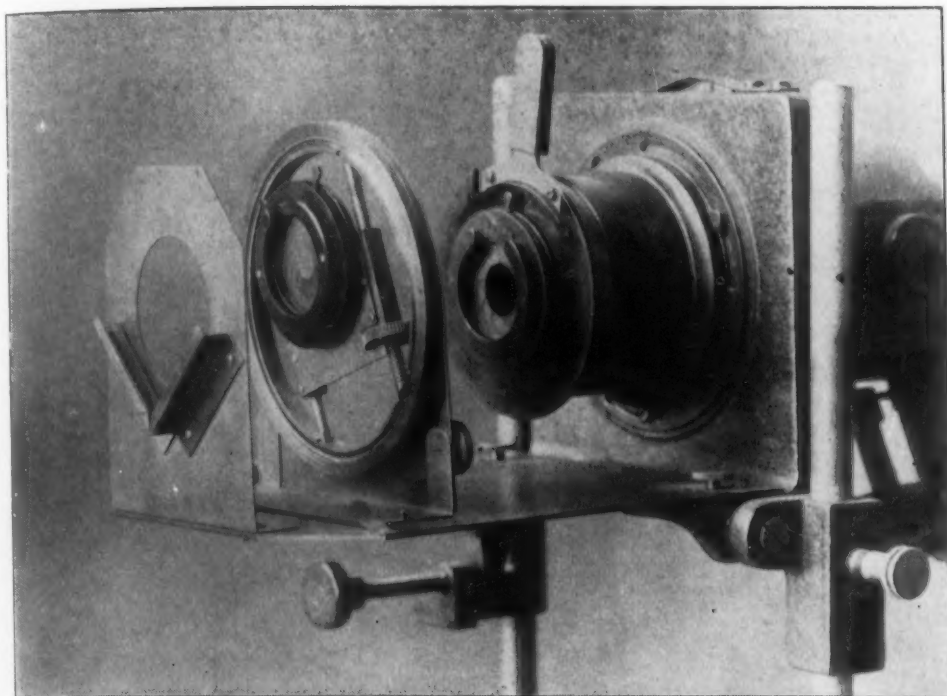


Fig. 4—Device for Obtaining Conical Illumination Using an Auxiliary Iris Diaphragm Mounted within a Wheel Whose Center is at the Optic Axis.

to require examination at higher magnifications, any method imparting a natural appearance should be adapted to high power lenses.

#### CONICAL ILLUMINATION DESCRIBED

The method described in this paper is applicable to all objectives for it is based on the fact that the objective itself is transmitting oblique as well as axial light to and from the object. Reference to Fig. 1 will make this clear. The arrangement shown is purely diagrammatic, the usual glass reflecting disc, stellite mirror and eyepiece being omitted for simplicity. Also, of course, in actual practice, the light source is not a point nor is it situated at the focal distance from the condenser. The design of the figure is merely to show clearly the fact that so-called axial illumination is really composed of true axial light and, also, of oblique light.

Light traveling approximately parallel to axis AA of the lens system (axial light) falls normally upon the object and masks

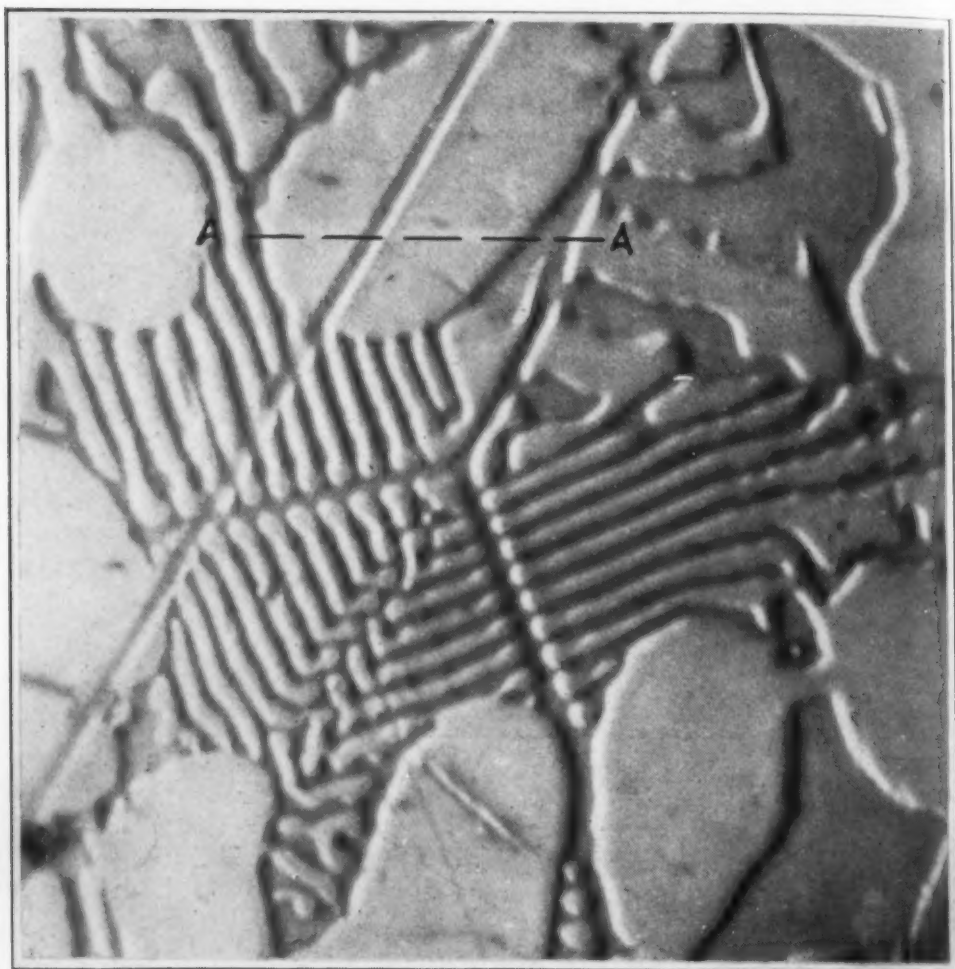


Fig. 5—Photomicrograph of Etched, Complex Alloy Under Conical Illumination. This Photomicrograph Shows the Same Field as Fig. 5-R (Opposite Page), but, in Photographing, the Direction for Illumination for Fig. 5 was from Left to Right, While for Fig. 5-R it was from Right to Left. (x 4000, 1.9 mm. objective, 10.0 x eyepiece.)

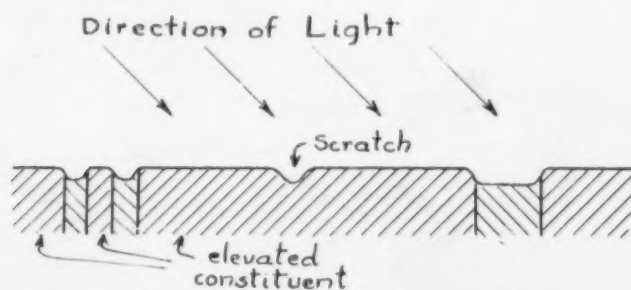


Fig. 7—Sketch Showing the Profile of Scratch (at AA, Fig. 5) Illustrating Method of Determining Direction of Light Used in Photographing.

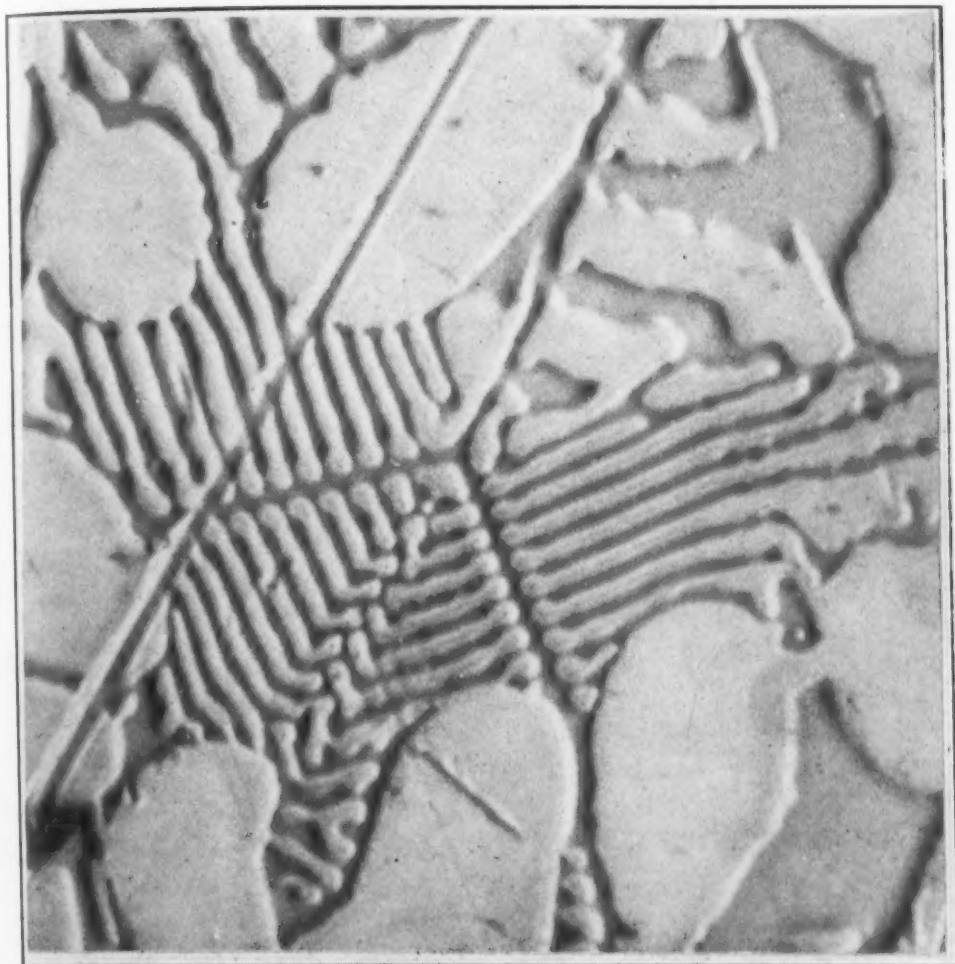


Fig. 5-R—Photomicrograph of same Field as Fig. 5. If Fig. 5 and Fig. 5-R are Illuminated by a Strong Light from the Left Fig. 5-R Usually Presents an Illusion, Making the Broad Light Areas Appear Depressed, Whereas in Reality They are Elevated as Usually Apparent in Fig. 5. (x 4000, 1.9 mm. objective, 10.0 x eyepiece.) Fig. 6 on Next Page Shows the Same Field with Ordinary Vertical Illumination.

any relief effect produced by the oblique light. To obtain relief, it is only necessary to stop out axial light. One way of doing this is to place an opaque disc in the illuminating beam perpendicular to the axis AA. (See Fig. 2.) An image of the disc is formed near the back lens of the objective, thus producing a hollow cone of light in the objective, having its apex on the object.

Since making this simple discovery, it has been pointed out to the writer that the method is essentially similar to oblique illumination by means of a substage condenser and stop in ordinary microscopic work with transmitted light. With reflected

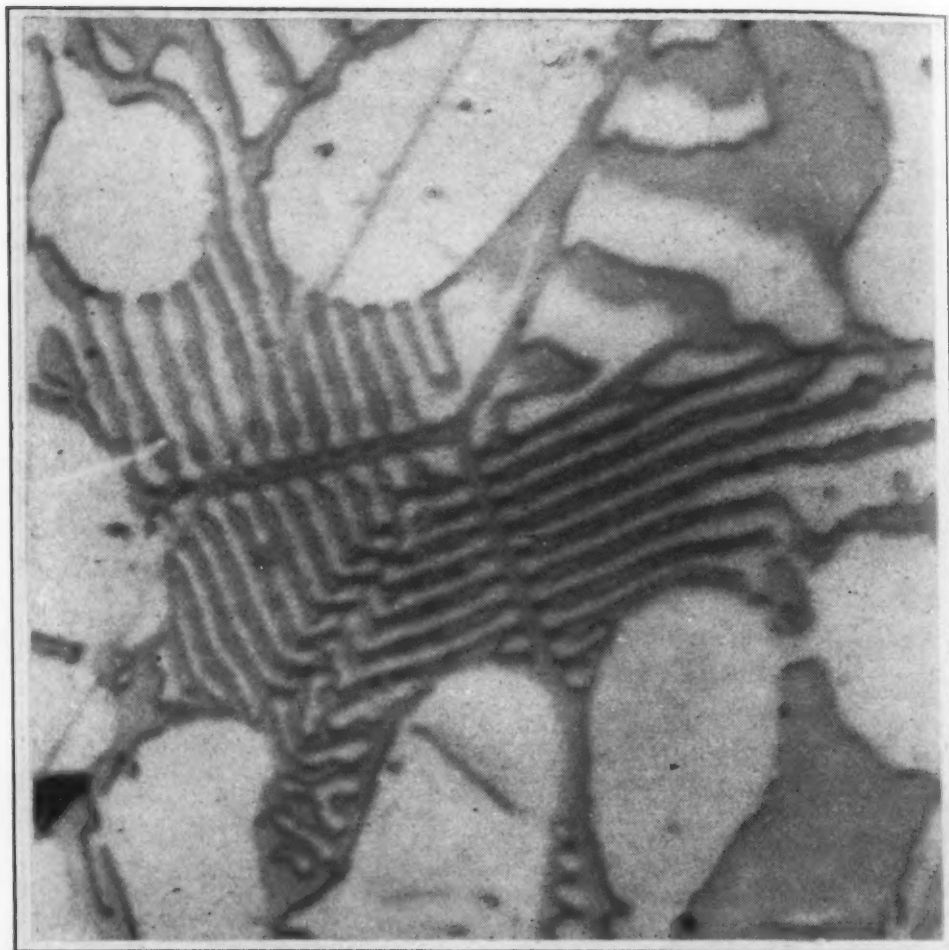


Fig. 6—Photomicrograph of Same Area as in Figs. 5 and 5R Taken with Ordinary Vertical Illumination. ( $\times 4000$ , 1.9 mm. objective, 10.0  $\times$  eyepiece.)

light and vertical illumination, the objective takes the place of the substage condenser and instead of placing a stop at the back lens of the objective, this method virtually places one there by the expedient of locating the image of one at that point.

The disc is preferably placed slightly eccentric so that light will fall upon the object from one direction. The particular direction of illumination, as well as the size of the disc, is best determined by trial for each individual subject and purpose.

While in some cases a definite, fixed size and position of stop is adequate, yet in most instances it is desirable to be able to rapidly change the size of stop and to rotate the direction of light.

For this purpose, the writer has had constructed the two devices illustrated in Fig. 3 and 4.

The contrivance shown in Fig. 3 is simply an assortment of stops of different sizes mounted on the spokes of a wheel. As the wheel is rotated, any stop can be swung into position. The arm on which the wheel is mounted is pivoted at its base so that the entire appliance can be swung out of the way. Any stop may be rotated about the optic axis by a compound rotary and pivotal motion of the wheel. The shadow of the stop on the filter affords a convenient means of noting its position.

The device illustrated in Fig. 4 serves the same purpose in a different way. It consists of an auxiliary iris diaphragm mounted within a wheel whose center is at the optic axis. The knurled adjusting nut controls the degree of eccentricity of the auxiliary iris. With the microscope nicely adjusted, the latter method is more conveniently operated than the one first described. Moreover, it is the more rugged in construction but has the disadvantages of requiring more accurate adjustment of the microscope and of cutting down the amount of light.

#### TERMINOLOGY

In the following, the term conical oblique illumination or simply conical illumination will be used to designate the method just described to distinguish it from oblique illumination as ordinarily applied. The terms vertical, normal and axial illumination refer to so-called vertical, that is, mixed axial and oblique illumination, commonly obtained when the object is illuminated through the objective.

#### MICROSCOPIC APPEARANCES

Oblique light as ordinarily applied is so nearly parallel to the surface of the object that it is not reflected from a perfectly plane surface through the objective to the eye because the angle of reflection equals the angle of incidence. Consequently, plane surfaces appear dark by ordinary oblique illumination and bright by ordinary vertical illumination. Rough surfaces, depressions, or elevations for the same reason, appear either light or dark depending on whether they are viewed by ordinary oblique or by ordinary

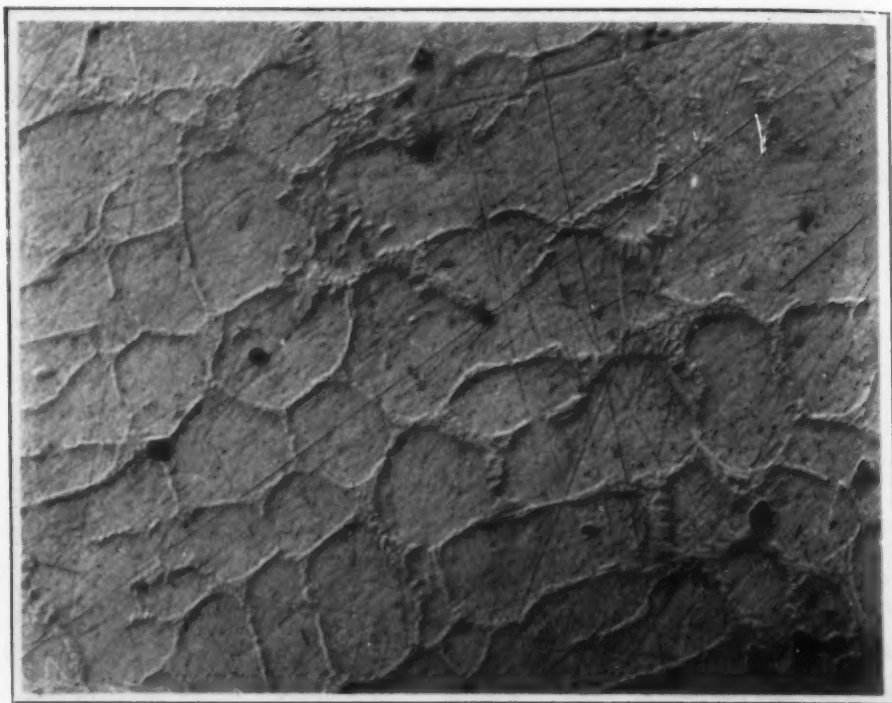


Fig. 8—Photomicrograph Under Conical Illumination of Etched Chrome-Iron Alloy, Showing Hard Carbide Standing in Relief in Eutectic Which Forms the Grain Boundaries. (x 250, 16 mm. objective, 6.4 x eyepiece.) Compare with Fig. 9.

vertical illumination. In other words, the view obtained by ordinary oblique light is the negative to the positive appearance obtained from ordinary vertical illumination.

Conical oblique light, on the other hand, does not give this negative appearance. The rays of light in this case are more nearly parallel to the optic axis and, therefore, are reflected back through the objective from plane surfaces, making them appear bright, as with so-called vertical illumination, and imparting a natural relief effect to the appearance.

#### CONICAL ILLUMINATION ADAPTED TO HIGH POWER

Resolution, which is the optical quality of differentiating or distinguishing as such two lines which lie side by side, is directly proportional to the numerical aperture of the objective. In general, the greater the aperture, the more resolution attainable. Also, the greater the aperture, the more oblique are the outer rays in the light cone, between the objective and object. It is also evi-

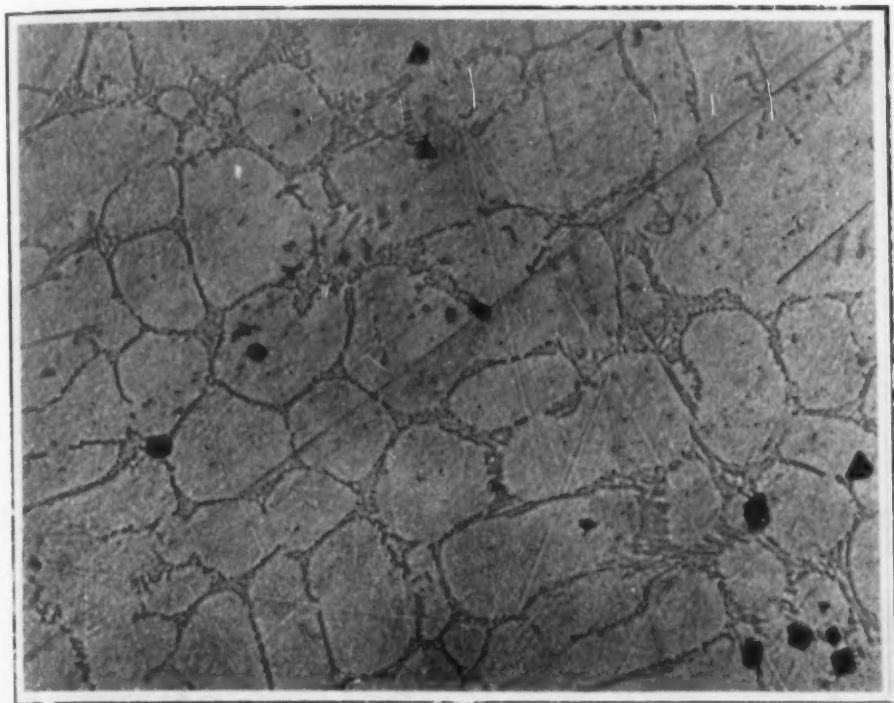


Fig. 9—Photomicrograph of the same Field as Fig. 8, Also Unetched, but taken with Vertical Illumination. Note absence of Relief in Fig. 9. (x 250, 16 mm. objective, 6.4 x eyepiece.)



Fig. 10—Photomicrograph of Unetched Chrome-Iron Alloy of High Carbon Content Under Conical Illumination (x 500, 4 mm. objective, 6.4 x eyepiece).



Fig. 11—Photomicrograph of Chrome-Iron Alloy Under Conical Illumination, Specimen Unetched, Structure Being Revealed by the Method of Lighting ( $\times 100$ , 16 mm. objective, 6.4  $\times$  eyepiece). Compare Fig. 12.

dent that immersion oil will increase the obliquity of the extreme rays because its index of refraction is greater than that of air. As the method of conical illumination depends for its effects on the obliquity of the light passing through the objective, it follows from the above optical considerations that it is particularly adapted to high power work.

#### ILLUSTRATIONS AND APPARATUS

The accompanying micrographs will illustrate the method in its application to low and high power objectives. They were taken with a Bausch & Lomb inverted metallurgical microscope and camera mounted on a horizontal bed. A Wratten B filter was used in conjunction with a direct current arc for illumination. Achromatic objectives and Huygenian eyepieces were used in all cases. The photographic plates were standard orthonon.

#### AN OPTICAL ILLUSION

With few exceptions the micrographs shown here, which were taken by oblique conical illumination are orientated the same with



Fig. 12—Photomicrograph of the Same Field Shown in Fig. 11, but Under Vertical Illumination. The Structure is Hardly Visible Owing to the Absence of Relief. ( $\times 100$ , 16.0 m.m. objective, 6.4 eyepiece.)

respect to the direction of light used in photographing which is, with respect to these pages, downward from left to right, at an angle of 45 degrees. The left side of elevations and the right side of depressions will then appear bright. The sense of sight is very easily deceived, however, and unless the direction of light used in photographing is known, it is impossible to tell, in the case of unknown structures, whether the appearance is real or an illusion. It will aid in avoiding the illusion if the light used in examining the micrographs be a strong one and have the same direction as that used in photographing.

One of the exceptions in orientation mentioned above is Fig. 5R which, when compared with Fig. 5 under a strong light from the upper left illustrates the illusion referred to. Under this condition of lighting most observers see Fig. 5R as the inverse of Fig. 5. The reason for this is that while the fields are orientated the same the direction of light was reversed in Fig. 5R. What are elevations in one seem to be depressions in the other. Turning the pictures upside down or allowing the light to come from lower right usually inverts the appearance of both pictures. When

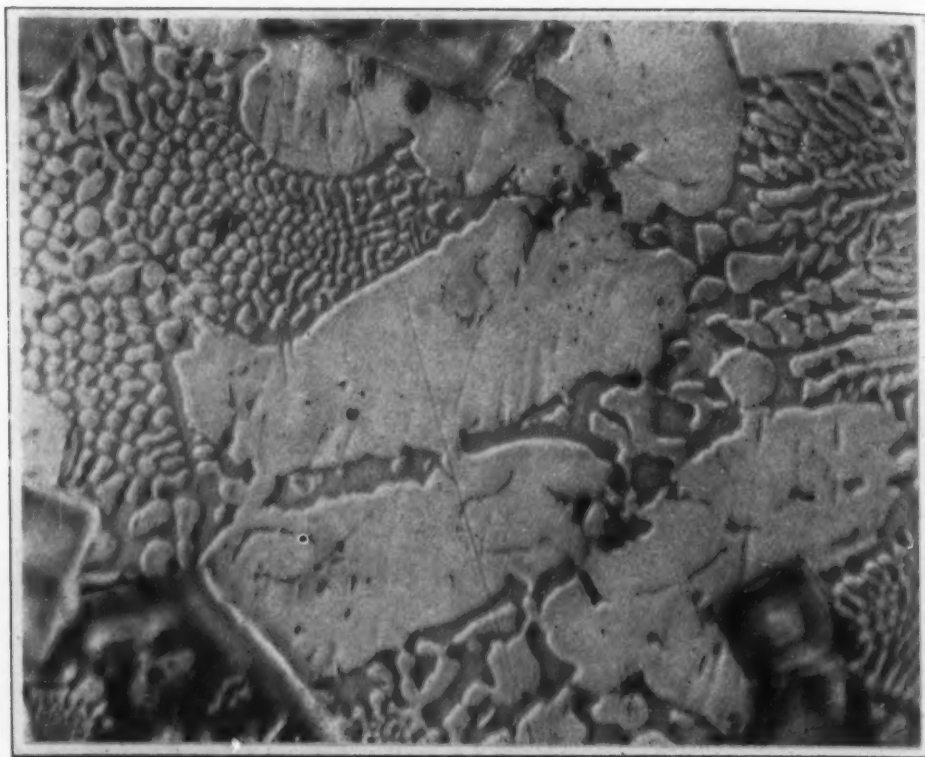


Fig. 13—Photomicrograph of Etched Complex Alloy Under Conical Illumination (x 2000, 1.9 mm. objective, 6.4 x eyepiece).

one is familiar with a particular structure the illusion rarely occurs irrespective of the direction of light used in photographing relative to that illuminating the picture. The illusion may also manifest itself while an object is being examined through the microscope, but only rarely with known structures or when a known detail such as a polishing scratch is visible in the field.

The point to be emphasized in connection with conical illumination is that in interpretation of structure, it is dangerous when examining an unknown structure to rely on appearances. For correct interpretation, the direction of illumination must be known. The facts of relief must then be deduced. If the appearance coincides with the deduction, it is real. If it does not, it is an illusion. When this process has been applied to a view which persists in being an illusion, it will suddenly invert and present the true appearance.



Fig. 14—Photomicrograph of the Same Field as Fig. 13 Under Vertical Illumination. (x 2000, 1.9 m.m. objective, 6.4 x eyepiece.)

#### VALUE OF POLISHING SCRATCHES

Because of the foregoing when examining an unknown structure, if this illusion proves confusing, it is advisable to analyze the structure with reference to a known surface detail such as a polishing scratch. If a scratch is large enough or under sufficient magnification it serves as a criterion to determine whether the illusion is present. Reference to Fig. 5 and 7 will make clear the use of a scratch in determining the direction of the light. Fig. 7 is a profile across the scratch at AA. From Fig. 5, it will be seen that the left side of the scratch is darker than the right, hence the light is coming from left to right as shown by the arrows in Fig. 7.

Incidentally, polishing scratches will be found to be of material assistance in determining structural characteristics, as for example, relative hardness and malleability of microconstituents. This application is brought out in Fig. 5, 8 and 10.

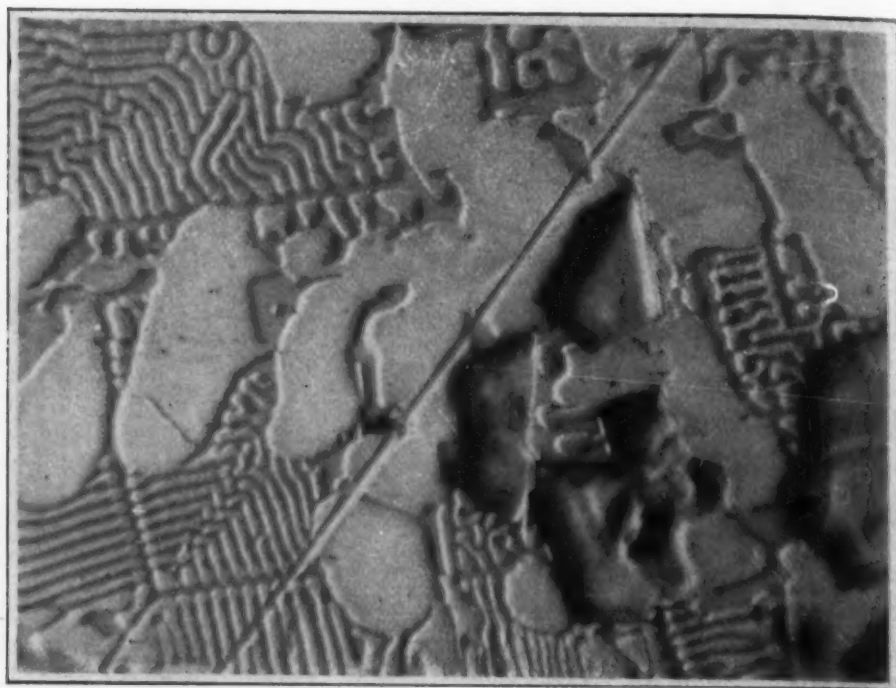


Fig. 15—Photomicrograph Under Conical Illumination of the same Field as Fig. 5, but at Lower Magnification. Angular Areas are Depressions, Rounded Patches are Raised. The Inverse Appearance is an Illusion. The Diagonal Line is a Polishing Scratch (depression). (x 2000, 1.9 mm. objective, 10 x eyepiece.)

#### PRACTICAL APPLICATION

The specimen shown in Fig. 10, is an alloy of 32.0 per cent chromium, 65.0 per cent iron and 3.0 per cent carbon, well known for its resistance to abrasion and its ability to withstand oxidation at elevated temperatures. The reason for the first quality, as clearly shown in Fig. 10, is the presence of a very resistant constituent held in a softer matrix. The hard constituent polishes in relief (the micrograph is of the unetched specimen) and even resists the abrasive particle which made the deep interrupted diagonal scratch across the field. Under vertical illumination, merely a faint tracery is visible with no relief and the specimen must be etched to reveal the structure. After etching, the scratch is no longer visible. Fig. 11 ( $\times 100$  unetched) illustrates the same combination of hard and soft constituents but in different proportions. Fig. 12 is of the same field as Fig. 11, but was taken with ordinary, so-called vertical illumination.

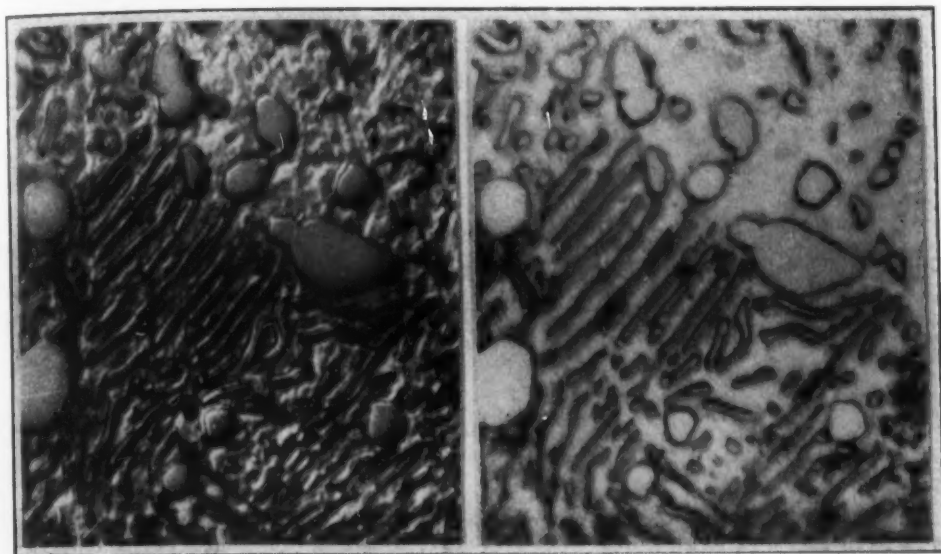


Fig. 16—Photomicrographs of 1.5 per cent Carbon Steel Showing Both Spheroidized and Lamellar Pearlite, under Oblique (conical) Illumination. Etched with 5 per cent Picric Acid in Alcohol. ( $\times 2000$ , 1.9 mm. objective, 10  $\times$  eyepiece.)

#### MODE OF DISCOVERY

Another interesting feature attending the use of oblique lighting is to be noted in Fig. 11, namely, the appearance in the same micrograph of structural details and nonmetallic inclusions. The usual method of developing structural details by etching, may mask or obliterate nonmetallic inclusions. In fact, it was in an effort to find some means of bringing out structure without obliterating inclusions that the method described was found. This application is brought out perhaps even more clearly in Figs. 8 and 9 ( $\times 250$  unetched) which are of the same material but at a higher magnification.

#### METHOD ILLUSTRATED

Fig. 10 ( $\times 500$ , unetched) has already been referred to. In this case, etching would undoubtedly develop the finer structural details to a greater extent. It will be noted in this and other examples that the magnification must be properly chosen to fit individual requirements.

Fig. 13 and 14 ( $\times 2000$ , etched) are of a different material at higher magnification, as is also Fig. 15 ( $\times 2000$ , etched).

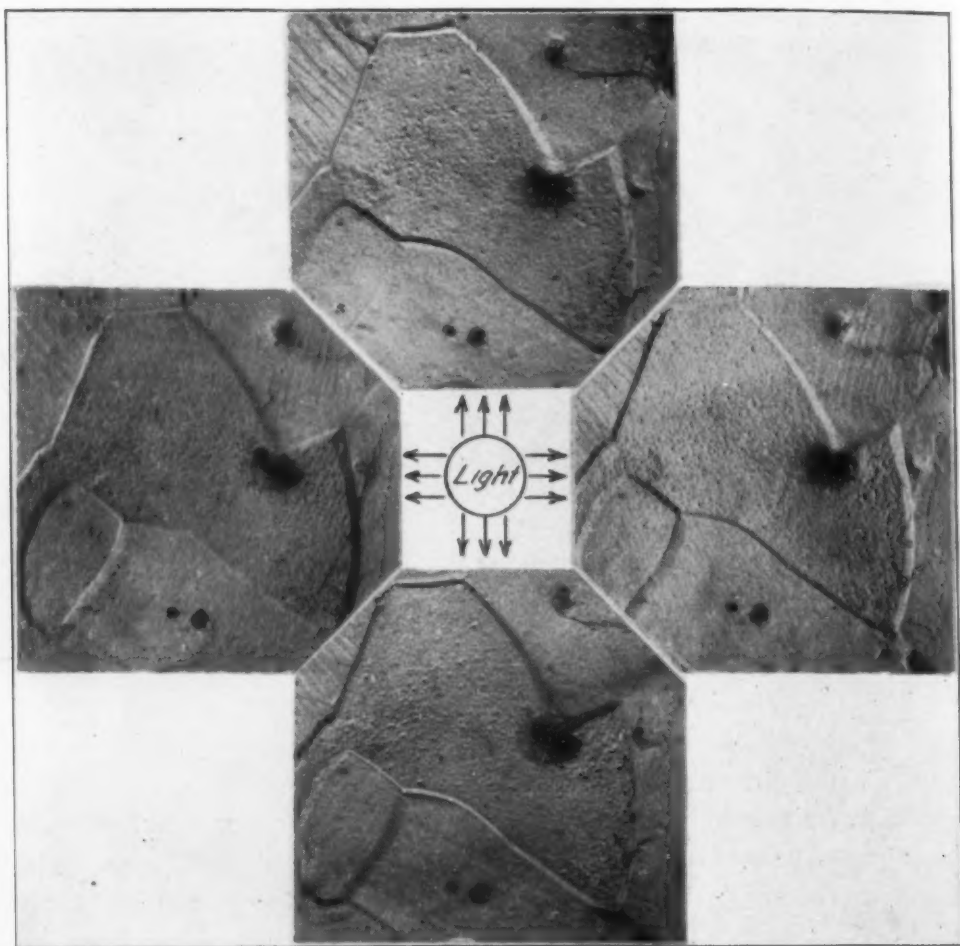


Fig. 18—Photomicrographs showing Grain Boundaries in Ferrite. This Figure Shows the Same Field under Conical Illumination from Four Directions as Indicated by Arrows. ( $\times 500$ , 4 mm. objective, 6.4  $\times$  eyepiece).

Incidentally, the angular material in Fig. 15 has been proven, by focussing measurements, to be actually deeply recessed by etching. This corroborates the evidence furnished by the scratch which runs diagonally across the field in Fig. 15, i.e., the field was lighted from the left and, therefore, the light colored areas, whose west slopes are lighted and whose east slopes are shaded, are plateaus. Likewise the angular areas, whose west sides are shaded and whose east sides are lighted, are hollows, etched out.

Fig. 5, 5R and 6 ( $\times 4000$ , etched) are of the same field as Fig. 15 but at twice the magnification. No advantage is derived from the higher magnification. It is apparent, however,

that magnification is no obstacle to this method. Fig. 5 and 5R have already been discussed, their purpose being to illustrate the optical illusion referred to.

Fig. 16 and 17 ( $\times 2000$ , etched) illustrate the familiar structure of pearlite but the combination of lamellar and spheroidal pearlite in the same field is rather unusual and offers a good subject to illustrate the advantage of conical over vertical illumination, as regards realism and attractiveness. The appearance of the iron carbide, cementite, standing in relief (Fig. 16) suggests this method as a means of distinguishing it from ferrite in grain boundaries instead of the usual treatment with sodium picrate.

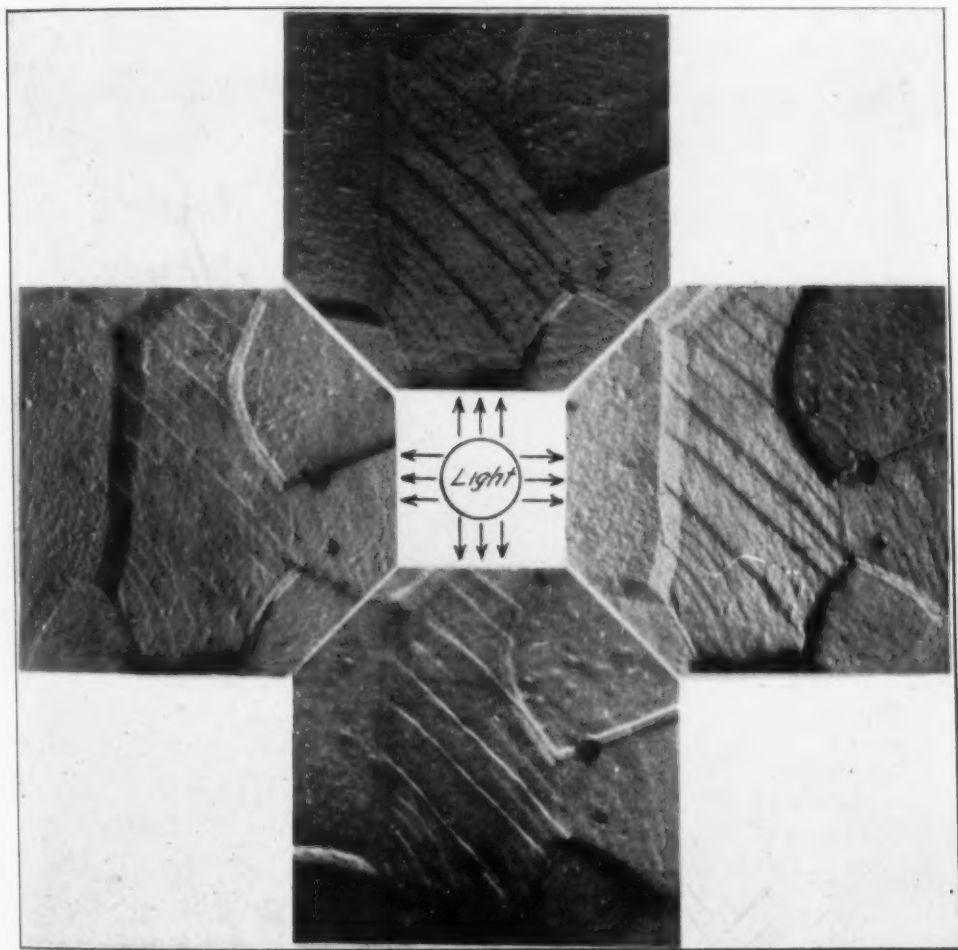


Fig. 19—Photomicrographs Showing Slip Lines and Grain Boundaries in Ferrite. This Figure Shows the Same Field Under Conical Illumination from Four Directions as Indicated by Arrows. ( $\times 1000$ , 1.9 mm. objective, 6.4 x eyepiece.)

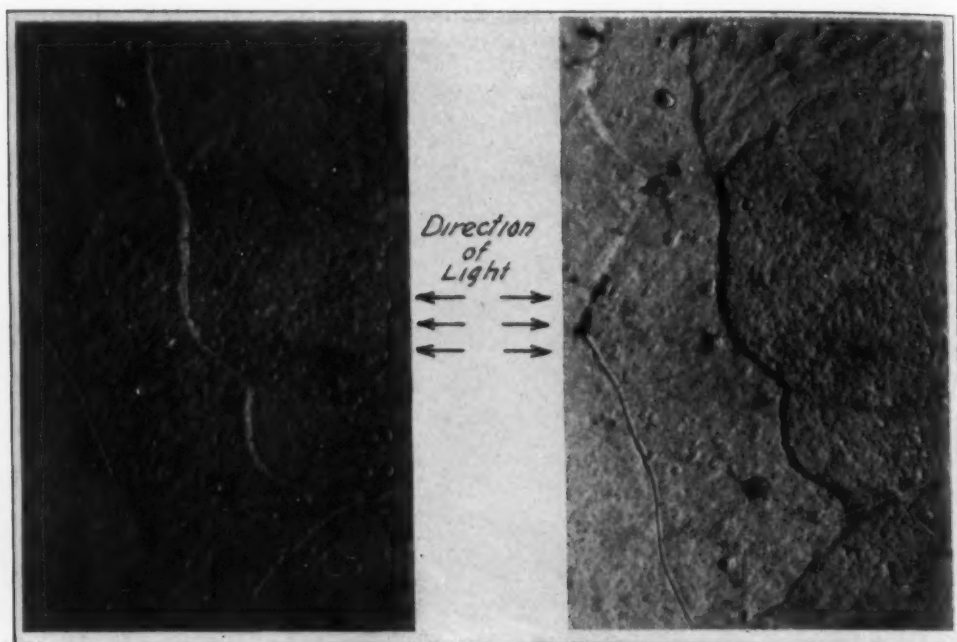


Fig. 20—Photomicrographs of Ferrite Grains under Conical Illumination from Opposite Directions as Indicated by the Arrows. Note "Step" and "Ditch" Types of Grain Boundaries. ( $\times 500$ , etched, 4.0 mm. objective, 6.4  $\times$  eyepiece.)

#### GRAIN BOUNDARIES UNDER CONICAL ILLUMINATION

In the introductory remarks of this paper the nature of grain boundaries was referred to. In the case of a pure metal, or of a solid solution, it has been inferred by some from focussing measurements that the surfaces of individual grains etch to varying depths owing to the differential existing between the rates of attack along different crystallographic axes. From this it is commonly conceded that black lines representing grain boundaries are really steps from one grain level to another. If this needs corroboration, it receives it from examination of grain boundaries under conical illumination. In Fig. 18 is shown the appearance of grains of ferrite etched with picric acid in alcohol, strained by compression, and magnified  $\times 500$  under conical illumination. A similar series, taken with oil immersion objective ( $\times 1000$ ) of a different field, is shown in Fig. 19.

The difference between the photomicrographs in Fig. 18 and 19 illustrates an interesting application of conical illumination similar in effect to that produced under ordinary oblique light



daries, several other features are revealed by these illustrations. Referring to Fig. 18, (upper and lower photomicrographs), the short horizontal grain boundary in the top center is evidently a ridge, for in the upper photomicrograph, its lower slope is lighted and its upper is dark, while in the lower photomicrograph, the reverse is true. Furthermore, the curving grain boundary in the center of the figure will be seen, at its horizontal sector, to be a combination of ridge and step. A third type of boundary is seen in Fig. 19 (right hand and left hand photomicrographs). The boundary between the central and lower left hand grains is evidently a ditch, both grains being at the same level. This type is more clearly shown in Fig. 20, showing Norway iron magnified 500 diameters. In this pair of photomicrographs, the particular boundary which illustrates the ditch type is the vertical one at the lower left of the field. In the left hand photomicrograph, lighted from the right, the left side of the boundary is bright, while in the right hand photomicrograph, lighted from the left, the right side is bright. By the same process, the parallel boundary in the center is seen to be a step, that is, the left central grain is higher than the right central grain.

An interesting etching phenomenon is to be seen in these two micrographs for which no explanation seems satisfactory. It will be noted that the left central grain is pitted while its neighbor, at a lower elevation, is pebbled. The writer has observed this condition to be consistent, that all grains which have been etched below their neighbors have pebbled surfaces while the higher ones are pitted.

Without digressing too far it may be worth while to mention some observations which have been made with the aid of conical illumination on the nature of grain boundaries. These observations by no means clear up the questions involved in this connection. Indeed they probably will complicate the present hypotheses. For example, does a ridge at a grain boundary indicate a more resistant material or does it indicate deposition during etching? And why are ridges not evident at all boundaries (of the same material)?

Fig. 21 depicts various types of grain boundaries observed under conical illumination in very mild steel. An attempt is made by dotted lines to reconstruct the grains, as they were before etch-

ing, and to indicate the continuation of boundaries below the surface. The unshaded portions represent metal removed by etching. It is thought that these sketches will be suggestive in themselves of various possibilities in the way of explanation.

Practical advantages of the method suggest themselves continually, not the least of which the writer has found to be the sense of pleasure and lack of fatigue attendant upon its use. Without doubt, this is the consequence of viewing objects in the microscopic field in their natural relationships.

In conclusion, the writer takes this opportunity to acknowledge his indebtedness to Dr. Ancel St. John for much helpful discussion and particularly for his suggestion of the term "conical illumination"; likewise to Dr. Thomas W. B. Welsh for helpful criticism in connection with the optical analysis of the subject; also to W. P. Melville for many suggestions and for the prints which accompany this article.

ABNORMAL GRAIN GROWTH IN COLD ROLLED LOW  
CARBON STEEL

By Victor E. Hillman and Frederick L. Coonan

*Abstract*

*This paper reviews the research work conducted in determining the factors and conditions causing abnormal grain growth in steel, resulting from annealing critically cold-rolled low-carbon steel. The four principal factors are carbon content, critical strain, temperature and time. The results show that a draft of 7.5 to 15 per cent should be avoided in cold-rolled steel used for vital parts.*

## INTRODUCTION

THE object of this research was to inquire into the underlying principles governing crystallization. The term "crystallization" as hereinafter used refers to that grain growth which is disclosed in low carbon steel when the metal is subjected to a certain degree of strain and temperature. In metallurgical parlance, this phenomenon is known as "Stead's brittleness."

In 1898, Stead discovered the presence of enormously large grains in soft steel. He found that if low carbon steel is subjected to a definite strain, and subsequently annealed at a temperature below the Ar<sub>1</sub> point, the ferrite grains undergo a marked crystalline transformation. That is to say, the adjoining ferrite grains merge to form a large grain. This coarse structure is decidedly detrimental to steel, causing the metal to suffer a noticeable decrease in its elastic limit, elongation, reduction of area, and fatigue resisting qualities.

## FACTORS AFFECTING GRAIN GROWTH

At the outset, it may be well to state that grain growth is a function of four factors; namely, carbon content, critical

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A paper to be presented before the annual convention of the Society to be held in Pittsburgh, October 8-12, 1923. Of the authors, V. E. Hillman is metallurgist and F. L. Coonan is assistant metallurgist with the Crompton & Knowles Loom Works, Worcester, Mass. Written discussion of this paper is invited.

strain, temperature, and time. Authors disagree to a slight extent as to the maximum percentage of carbon which will forestall crystallization. Some metallurgists claim that it cannot be developed in steel containing more than 0.15 per cent carbon, while others contend that the phenomenon continues to manifest itself until the carbon is in excess of 0.18 per cent. However, such subtle distinctions are merely of passing interest.

The development of critical strain is dependent upon the expenditure of energy. It is immaterial what agency is employed. In fact, any force that causes the ferrite grains to assume the same orientation, supplies the first requisite for grain growth. Therefore, when low carbon steel is cold rolled, sufficient pressure may be exerted to produce critical strain. On subsequent annealing, crystallization will result providing the operation is conducted at a specified temperature slightly below the Ar<sub>1</sub> point. Hence, the aim and purpose of this investigation was designed to serve a triple purpose; first, to ascertain the degree of draft in cold rolling which will produce critical strain, second, to determine the temperature range in which grain growth becomes apparent, third, to decide what influence various percentages of carbon exert on the mechanism of grain development.

This research required three grades of basic open-hearth steel, namely, 0.08 per cent carbon; 0.10 per cent carbon; and 0.13 per cent carbon, with the other elements normal. Previous to the application of cold work, the steel was annealed for the purpose of relieving such strains as might have been induced as a result of hot rolling.

#### PROCEDURE—0.08 PER CENT CARBON STEEL

A strip of stock—4 feet long by 6 inches wide was given a pass through a mill of the ordinary cold rolling type. The metal suffered a reduction in thickness of 2 per cent. A test specimen 7 inches long by 6 inches wide was cut off for experimentation. The remaining product was again reduced in thickness 3.5 per cent, whereupon another sample was procured. This scheme of procedure was continued until samples repre-

senting the following reductions in thickness were obtained; namely:

Reduction per cent	Reduction per cent	Reduction per cent
2.0	15.0	61.0
3.5	19.0	66.0
4.0	21.0	68.0
5.0	29.0	72.0
7.5	35.0	75.0
8.0	40.0	77.0
10.0	48.0	80.0
14.0	58.0	

This method of procedure produced 23 samples representative of various degrees of cold work. It was reasonable to assume, therefore, that some of the specimens had been critically strained. The 23 specimens were annealed at 1250 degrees Fahr., for a period of 8 hours. The reason for selecting this temperature will be hereinafter noted. Micro-examination revealed full and complete grain growth in the specimen which received a 7.5 per cent reduction in thickness. In the section reduced 10 per cent a few large crystals and a semi-growth were detected. The character of the latter structure resembled a transition stage. Similar features were observed in the specimens which had received a draft of 14 and 15 per cent.

Observations point to the conclusion that as the degree of draft approaches 15 per cent there appear (at 7.5 per cent reduction) very large grains, second, (at 10 and 14 per cent reduction) semi-growth and finally, as the strain exceeds the "critical" (15 per cent reduction) the grains revert to the characteristic structure of an anneal below the Ar<sub>1</sub>. Therefore, the critical strain occurred within a reduction range of 7.5 to 15 per cent inclusive. It is to be noted, however, that the maximum crystalline growth occurred at 7.5 per cent reduction.

The specimens which were reduced,

Per Cent	Per Cent	Per Cent
19	48	
21	58	75
29	61	77
35	66	80
40	72	

developed no increase in grain size. Hence, these specimens were strained beyond the critical point. It might be said that they were over-strained. By the same token, the specimens which were given a draft reduction of 2, 3.5, 4 and 5 per cent may be designated as understrained, for the reason that crystalline growth did not develop during the thermal treatment.

#### TEMPERATURE RANGE—PRODUCTIVE OF CRYSTALLINE GROWTH

Abnormal grain growth in critically strained steel is confined to definite temperature limits below the Arl point. Moreover, carbon plays an important role in regulating this growth-producing temperature range. Observations pointed to the fact that as the carbon content of the steel approached 0.15 per cent the temperature range in which coarse crystallization occurred was confined to narrower limits.

For the purpose of determining the extent of this variance, three grades (0.08, 0.10 and 0.13 per cent carbon) of critically strained steel were annealed at the following temperatures for 8 hours;

Degrees Fahr.	Degrees Fahr.
1150	1400
1250	1450
1300	1500
1350	

In the 0.08 per cent carbon steel, a slight degree of coarse crystallization was in evidence in the specimens annealed at 1150 degrees Fahr. Complete growth occurred at 1250, 1300, 1350, 1400 and 1450 degrees Fahr., whereas, at 1500 degrees Fahr., no growth was discernible. Therefore, the growth-producing range is between 1150 and 1450 degrees Fahr. for an 0.08 per cent carbon steel.

In the 0.10 per cent carbon steel, grain growth occurred at 1250, 1300, 1350, 1400 and 1450 degrees Fahr., whereas in the 0.13 per cent carbon steel, coarse crystallization took place at 1300, 1350, 1400 and 1450 degrees Fahr. Hence, the growth-producing temperature range for 0.10 per cent carbon steel lies between 1250 and 1450 degrees Fahr., while on the other hand, the development range for a 0.13 per cent carbon steel is between 1300 and 1450 degrees Fahr.

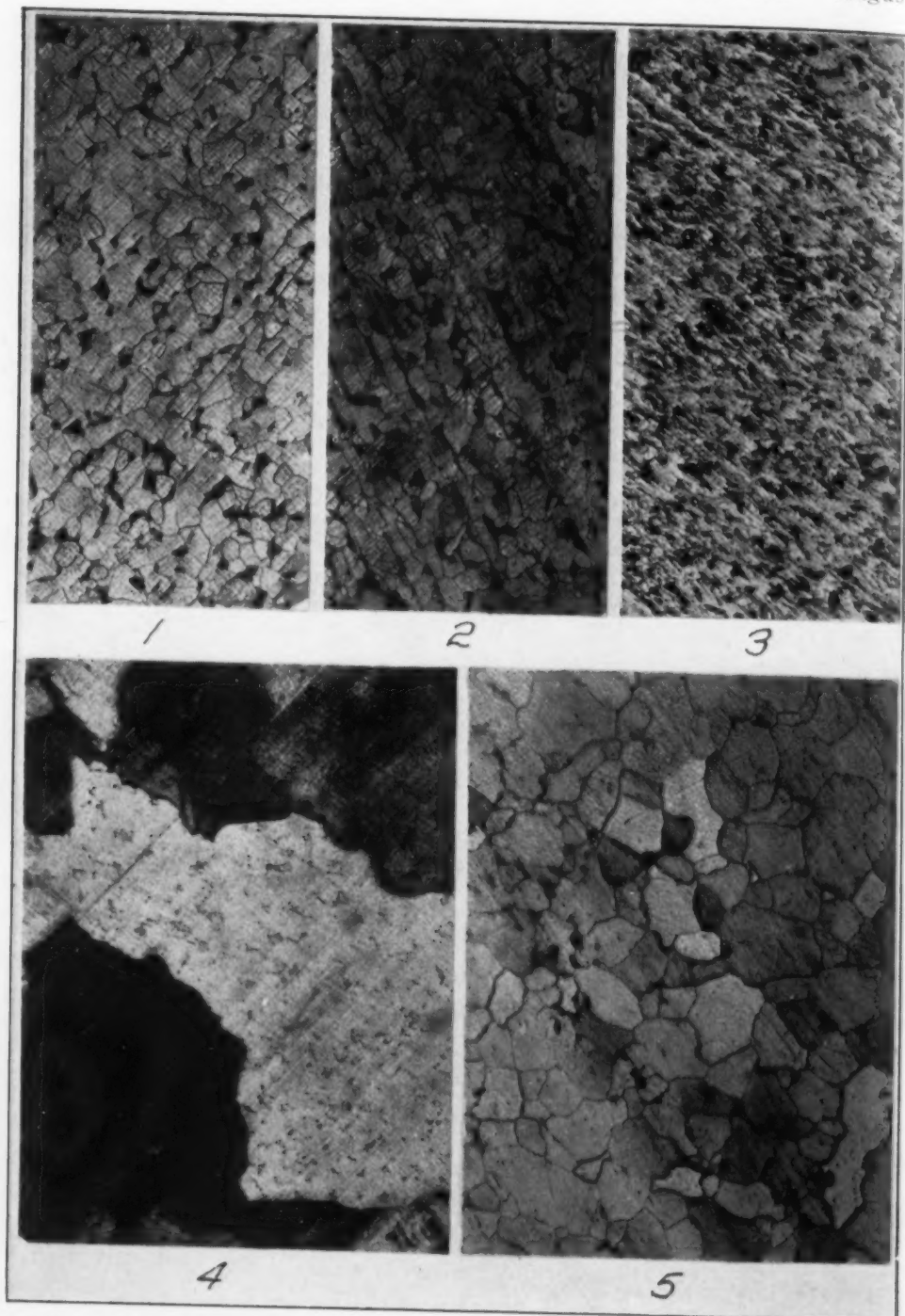


Fig. 1—Photomicrograph of Annealed 0.03% Carbon Steel Before Cold Working or Heat Treating. Fig. 2—Photomicrograph of 0.08% Carbon Steel After a 7.5% Reduction by Cold Work. Fig. 3—Photomicrograph of a 0.08% Carbon Steel After a Cold Reduction of 66%. Fig. 4—Photomicrograph of 0.08% Carbon Steel Annealed at 1250 degrees Fahr. for 8 hours after a Cold Reduction of 7.5%. This Enormous Grain Growth was Developed by Annealing. Fig. 5—Photomicrograph of 0.08% Carbon Steel Annealed for 8 hours at 1450 degrees Fahr. after a Cold Reduction of 14%. All Photomicrographs  $\times 100$ .

## METALLOGRAPHIC OBSERVATIONS

Photomicrograph, Fig. 1, shows a specimen of annealed 0.08 per cent carbon steel. It will be noted that the pearlitic particles show no evidence of cold work. Moreover, the ferrite grains are equi-axed.

Fig. 2 shows the effect of cold rolling a 0.08 per cent carbon steel. The specimen received a reduction in thickness equivalent to 7.5 per cent. This specimen was critically strained. The elongated grains are especially noticeable in the pearlitic areas. Note particularly the appearance of the metal in the "as-rolled" condition, free from heat treatment.

Photomicrograph, Fig. 3, shows the effect of excessive cold work on 0.08 per cent carbon steel, in which a reduction in thickness of 66 per cent has been effected. The highly strained condition of the metal is plainly evident, the crystals being elongated in the direction of rolling. The specimen has been strained beyond the "critical," and the crystals have assumed a ropey appearance resembling fiber. Hence, annealing within the danger zone (1150—1450 degrees Fahr.) will not develop crystalline growth.

The microstructure of a 0.08 per cent carbon steel which has been cold rolled to a reduction in thickness of 7.5 per cent is shown in Fig. 4. The specimen was annealed for 8 hours at 1250 degrees Fahr. The photomicrograph shows the enormous grain growth, which thermal treatment developed. It should be borne in mind, however, that a critical strain (namely 7.5 per cent draft) was a pre-requisite to the creation of this structure.

Fig. 5 shows the microstructure of a 0.08 per cent carbon steel cold rolled to a 14 per cent draft. This specimen was annealed at the upper limit (1450 degrees Fahr.) of the danger zone for 8 hours. The photomicrograph (Fig. 5) shows a transition stage in the specimen as evidenced by the semi-growth of the crystals. They are neither excessively large nor minute.

Photomicrograph, Fig. 6, is that of a 0.08 per cent carbon steel having had a 66 per cent draft and then annealed within the hazardous range, namely 1250 degrees Fahr. for 8 hours. It will be observed that no grain growth has taken place. This

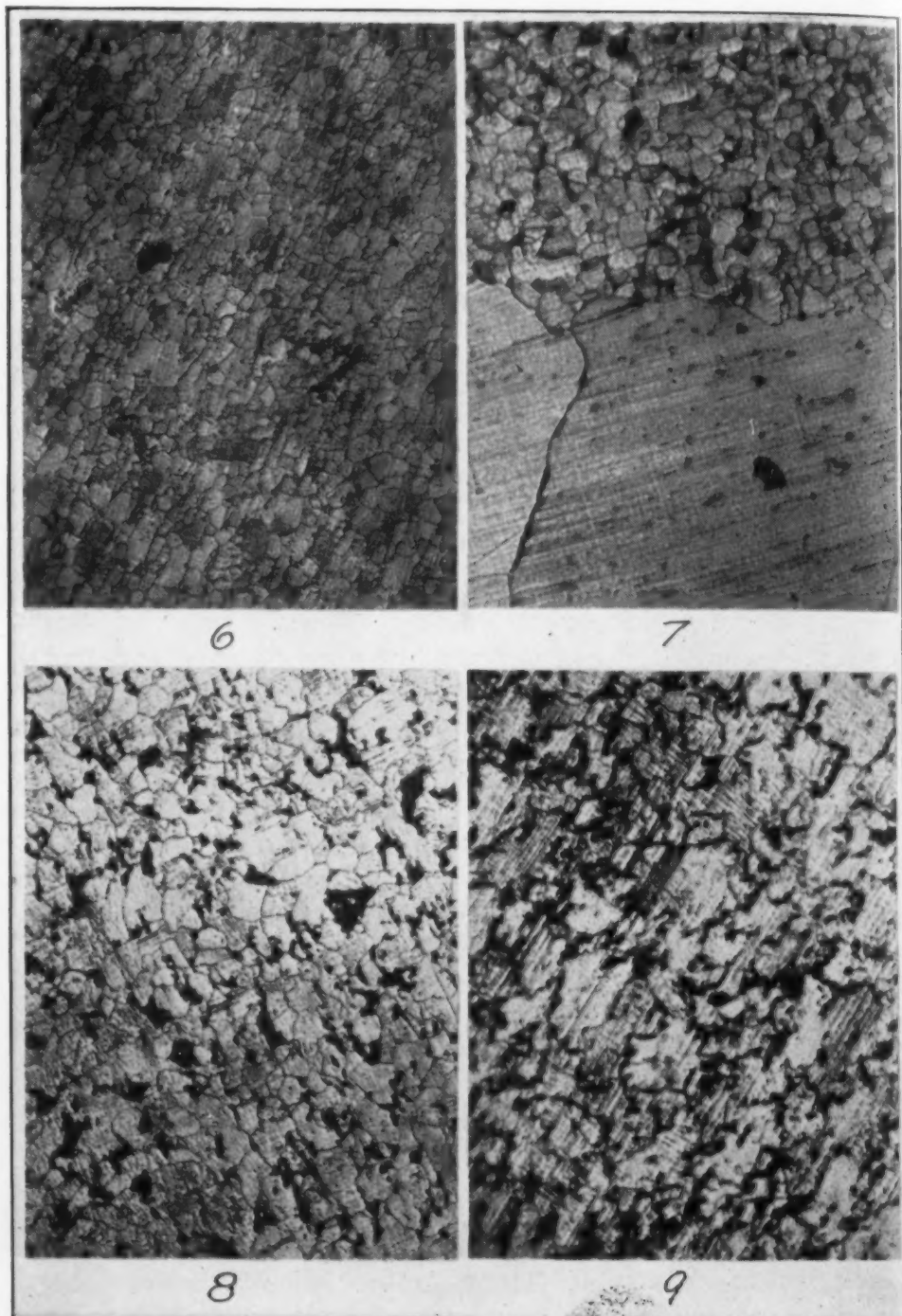


Fig. 6—Photomicrograph of 0.08% Carbon Steel Annealed for 8 hours at 1250 degrees Fahr. After a Cold Reduction of 66%. Ferrite Particles are Returning to Normal while the Pearlite Remains Elongated. Fig. 7—Photomicrograph of 0.08% Carbon Steel Annealed 8 hours after a Cold Reduction of 7.5%. Apparently the Metal has been Subjected to an Inequality of Pressure. Fig. 8—Photomicrograph of 0.08% Carbon Steel Critically Strained (14%) Annealed at 1500 degrees Fahr. for 8 hours. Fig. 9—Photomicrograph of 0.15% Carbon Steel Annealed at 1250 degrees Fahr. after a Cold Reduction of 14%. All Photomicrographs  $\times 100$ .

steel was annealed at a temperature which would have developed crystalline growth if the metal had been critically strained. The only influence which the thermal treatment exerted on this specimen was to convert the elongated ferrite areas to their former equi-axed condition. The pearlitic particles remain unaffected. A similar structure was observed in specimens which were reduced in thickness as follows:

Per Cent	Per Cent	Per Cent
19	48	
21	58	75
29	61	77
35	68	80
40	72	

Fig. 7 shows an interesting side light on the development of crystalline growth in a 0.08 per cent carbon steel which was reduced in thickness 7 per cent, and annealed at 1250 degrees Fahr. for 8 hours. Apparently, the metal has been subjected to an inequality of pressure.

The explanation of this erratic performance may be attributed to the fact that the force of cold rolling was not sufficiently uniform to cause all of the grains to become critically strained. It may be remarked that where a specimen receives a tapering deformation, there always exists a sharp line of demarcation differentiating the critically strained from the under-strained grains.

Photomicrograph, Fig. 8, shows a 0.08 per cent carbon steel critically strained (14 per cent) and annealed at 1500 degrees Fahr. for 8 hours. Although the metal has been critically strained, crystalline growth failed to develop because the metal was subjected to a temperature beyond the upper limit (1450 degrees Fahr.) of the hazardous zone.

Fig. 9 is a photomicrograph of a specimen of 0.15 per cent carbon steel cold rolled to 14 per cent reduction in thickness, annealed at 1250 degrees Fahr. for 8 hours. It will be observed that the metal contains a relatively large percentage of pearlite. The presence of this microconstituent stands in the way of the ferrite grains and prevents them from merging to form crystalline growth.

## CONCLUSIONS

In formulating a summary of this work it has been subdivided into 5 parts.

I. The degree of draft which will produce a critical strain in cold rolled steel occurs when the metal receives a reduction in thickness of 7.5 to 15 per cent inclusive.

II. In critically strained cold rolled steel the growth producing range is between 1150 and 1450 degrees Fahr.

III. The aforementioned temperature limits vary according to the carbon content of the metal, namely;

Carbon per cent	Temperature degrees Fahr.
0.08	1150-1450
0.10	1250-1450
0.13	1300-1450

IV. A draft of 7.5 to 15 per cent should be avoided in cold rolled steel which is used for vital parts. This procedure will prevent crystalline growth in the event that the parts are subjected to service temperatures which lie within the danger zone (1150 to 1450 degrees Fahr.).

V. Increasing the carbon content of the metal beyond 0.18 per cent will effectively prevent crystalline growth regardless of the degree of strain or temperature.

## CARBURIZATION OF STEEL

By B. F. Shepherd

*Abstract*

*This paper specifically studies the continued use of carburizing compounds as it affects the character of the case produced. The influence of increased carburizing temperature, the effect of time variation, the influence of time and temperature upon the character of the case and the relationship in carburized and hardened chrome-vanadium steel between scleroscope hardness, carbon content and penetrability as measured by the Brinell method at different zones in the case, is studied in detail. Numerous curves and data sheets accompany this paper.*

## INTRODUCTION

CARBURIZATION, cementation or case-hardening is the term used for any method of increasing the carbon content of a piece of iron or steel, without melting it. The action takes place with the greatest intensity on the surface, gradually forming an outer zone or case which becomes wider as the absorption of carbon continues. Two distinct applications are made of this phenomenon, one called total cementation, when the piece is completely changed to a high carbon steel, and the other partial cementation. In the latter case, the carburizing action is checked or stopped when the zone or case, is of the desired depth and carbon content. The former is used for the manufacture of special quality high carbon tool steel and the latter with which we are principally interested for the heat treatment of machine parts, to withstand difficult service conditions.

## HISTORICAL

The first mention of the carburization of iron or steel was published in the year of 1540, the method described, consisting in heating billets of soft iron for a long period of time in molten

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A paper presented before the Eastern Sectional meeting of the Society, Bethlehem, Pa., June 14, 1923. The author B. F. Shepherd is in the metallurgical department of the Ingersoll-Rand Co., Phillipsburg, N. J.

cast iron. The soft iron, being much lower in carbon content than the cast iron, absorbed carbon from it.

In the sixteenth century many processes were used for the superficial or surface hardening of finished objects. During this period the process was applied to transforming iron into steel which was later forged to shape. The 'secret formulas' for these processes were handed down from father to son, and it was not until 1720 that the French scientist Reaumur made a scientific investigation of the process. In 1740, Benjamin Huntsman melted in a crucible, Swedish bar iron which had been increased in carbon by cementation, and produced a high grade steel. Other methods of manufacturing steel at lower prices gradually forced this process from the market, but it is still used in a very small extent in England.

#### GENERAL

Owing to the difficult service requirements to be met by modern machinery, the use of case-carburizing as a method of heat treatment has increased very materially. The process creates a steel capable of being made extremely hard and wear-resistant on the outside and having a strong, tough, inner portion or core. This type of structure is suitable for parts which are required to stand considerable shock and friction. Parts which are required to be hardened only on portions of the total area may be rough machined and carburized and the higher carbon regions removed, by machining it from the areas which are desired soft. The added advantage of being able to machine a softer and cheaper material and subsequently making it surface hard by carburizing, materially lessens the cost of the part. Engineers often lose sight of the problems encountered in the heat treating department and design parts of complicated form which are to be hardened on the surface. If these parts are made of high carbon tool steel, the hardening operation usually becomes hazardous due to the tendency of complicated sections to crack during the quenching operation. The use of a carburizing steel makes the operation less hazardous from the standpoint of tool breakage.

Carburization depends upon the ability of iron and steel to absorb carbon when heated in contact with a carbonaceous material. The primary factors which influence the results are,

the length of time the piece is exposed to the temperature, the temperature, the carburizing material, and the composition of the steel. As a general rule, the higher the temperature and the longer the time, the deeper will be the case.

The carburizing steels in general use are selected according to the service requirements of the parts which are to be made from them. The selection of these steels should be studied very carefully. The carburizing process cannot remove imperfections, irregularities or faults in the steel. It will magnify them. As a general rule parts should not be made of a carburizing steel if it is possible to obtain satisfactory service from an oil or water hardening steel properly heat treated. The equipment needed for the carburizing operation, the materials used, the time consumed and the careful supervision required cause a heavy labor and overhead charge resulting in an increased cost of the finished part.

The type of steel, the heat treatment which the part is to receive, and the machineability of the steel are of considerable importance. Several well known types of steel should be adopted as standard. It is usually desirable that these should conform to the specifications of societies such as the Society of Automotive Engineers and the American Society for Testing Materials. In some special cases it may be necessary to specify a special analysis steel, but adherence to a few standard steels will result in better service from the steel manufacturer when business is booming and steel is hard to obtain. It also means that less steel will be required for stock purposes as the sizes for the various parts will duplicate and a smaller quantity in stock will meet all demands. A better knowledge of methods of handling in the heat treating department will result, as familiarity with certain well known types increases.

Each type of steel should be procured from several manufacturers, and after experience has shown the quality which each has furnished they should be graded and purchased accordingly. The steel, when received should be carefully inspected for chemical composition, surface, size, seams and occasionally fracture and micro-structure.

#### CARBURIZING MATERIALS AND METHODS

The method of carburization varies with the cement or

carburizing compound used. The different types of carburizing compounds may be roughly classified as solid carburizers, which represent the great bulk of commercial carburizers; liquid carburizers, gases and mixed cements. The latter term is used by Giolitti and consists of a combination of carbon monoxide gas and charcoal.

The solid cements are usually granulated materials such as wood charcoal, raw bone, charred bone, bone impregnated with oils, charred leather, coke and coal compounds impregnated with an energizer. Liquid cements are usually molten cyanogen salts.

The purpose of this paper is to discuss the results of certain tests made upon several commercial solid carburizing compounds for the purpose of ascertaining and correlating certain data which are factors surrounding the carburizing operation. These data have been illustrated, mainly by carbon concentration diagrams and also show the difference in characteristics, weight, cost, etc., of eight different commercial compounds. The factors studied are:

1. The effect of continued use of the compounds under test upon the depth and character of the case produced in a chrome-vanadium steel.
2. The influence of increased carburizing temperature upon the depth and character of the case produced in the same type steel by these compounds.
3. The effect of variation in time upon the depth and character of the case produced by a commercial compound on two steels, a simple carbon and a chrome-vanadium steel.
4. The influence of time and temperature upon the depth and character of the case produced by a shop mixture of a well known commercial compound on a chrome-vanadium steel.
5. The relation in a hardened chrome-vanadium steel between scleroscope hardness, carbon content and penetrability as measured by the Brinell method at different zones in the case.
6. The depth and character of case produced in a chrome-nickel steel as compared with a chrome-vanadium steel.

#### PROCEDURE

The method of procedure employed is as follows: The test pieces for each series run were 5 inches long and from the same

bar of steel. The bar was a  $2\frac{1}{4}$ -inch round and the test pieces were machined and finished to 2 inches round, by grinding. The short stocky bar minimized the possibility of distortion and



Fig. 1—Type of Carburizing Box Used in these Tests.

the large diameter gave a sample with an 0.005-inch cut sufficiently ample to permit of a representative chemical determination. The pieces were packed with a  $\frac{1}{4}$  cubic foot, loose measurement, of compound in an alloy carburizing box  $12\frac{1}{2} \times 6\frac{1}{2} \times 7$  inches deep inside dimensions, the recessed lid of the box being luted with clay. The type of box used is shown in Fig. 1.

Eight hours were taken to heat the boxes through to 1600

degrees Fahr., other temperatures in proportion. When the boxes were held for the number of hours noted, they were removed and allowed to cool in the atmosphere. The temperature was measured with a standardized potentiometer recorder, held to within plus or minus 15 degrees Fahr. and checked during the

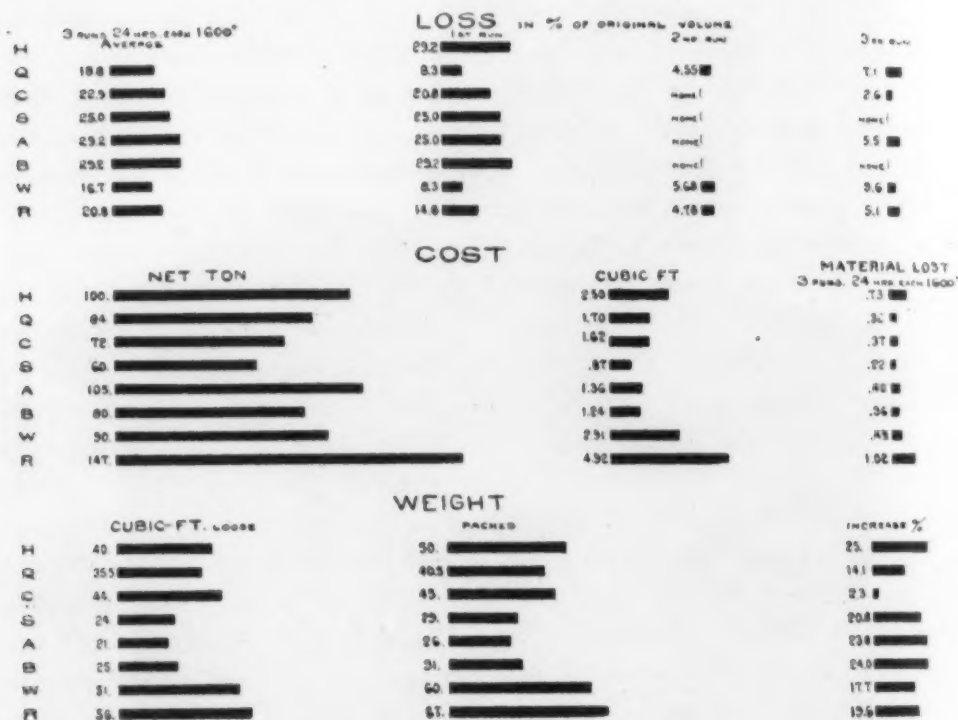


Fig. 2—Shows the Difference in Weight and Cost of Eight Different Commercial Carburizers Together with the Loss of Compound Obtained in Three Runs of 24 Hours Each.

run with a portable potentiometer. An additional thermocouple was in the furnace during the entire period of the heat, spaced 4 to 5 feet from the first thermocouple, this being used to check the uniformity of the furnace temperature. The furnace was fuel oil-fired and of a construction which ensured uniform heating of the boxes which were carefully spaced on and held off of the furnace hearth by legs  $1\frac{1}{2}$  inches high.

#### WEIGHT, COST AND SHRINKAGE

Fig. 2, shows the difference in weight and cost of eight different commercial carburizers together with the loss of com-

pound obtained in three runs of 24 hours each after heated through at 1600 degrees Fahr.

The lower set of figures show the great difference existing in the specific gravity of commercial compounds. As these materials are purchased by weight and used by volume the lightest compound will be the cheapest as it will fill more boxes. Of two compounds having the same carburizing properties, price and specific gravity, the one which does not settle excessively when packed will be the cheapest. Compounds which settle excessively when packed must be used carefully or part of the work may be uncovered when the box is placed in the furnace.

The middle set of figures shows the relation between the initial price, the price per cubic feet and the cost of the material lost by shrinkage during three runs. Compound "S" was the cheapest compound although the specific gravity was about the same as compounds "A" and "B."

The initial low price of this material was not made without reason, as the carbon concentration curves show it to be very erratic and to actually produce decarburization in one run. It is a cheap coke-charcoal compound, impregnated with energizer and made to sell. Compound "A" is lighter than "B" and has approximately the same percentage increase in weight when packed. The difference in weight brings the price per cubic foot very close to that of "B."

The influence of the increase in weight when packing a compound is seen in the comparison of "C" and "Q." The latter has the highest price per ton but is also the lighter and comparison on this basis makes it the cheaper, i. e., \$1.58 for "C" against \$1.49 for "Q." It has a larger increase in weight when packed and this causes the costs to be reversed and the compound with the low percentage of weight increase is found to be the cheaper of the two, i. e., \$1.62 for "C" against \$1.70 for "Q." The influence of weight of the compound is seen in the heavier compounds showing that the market price is not an indication of the cost as used.

A comparison of the shrinkage data or loss of compound seen in the top set of figures shows a great variation. It is much better for a compound to shrink gradually than to have a high initial shrinkage. The possibility is always present of some of

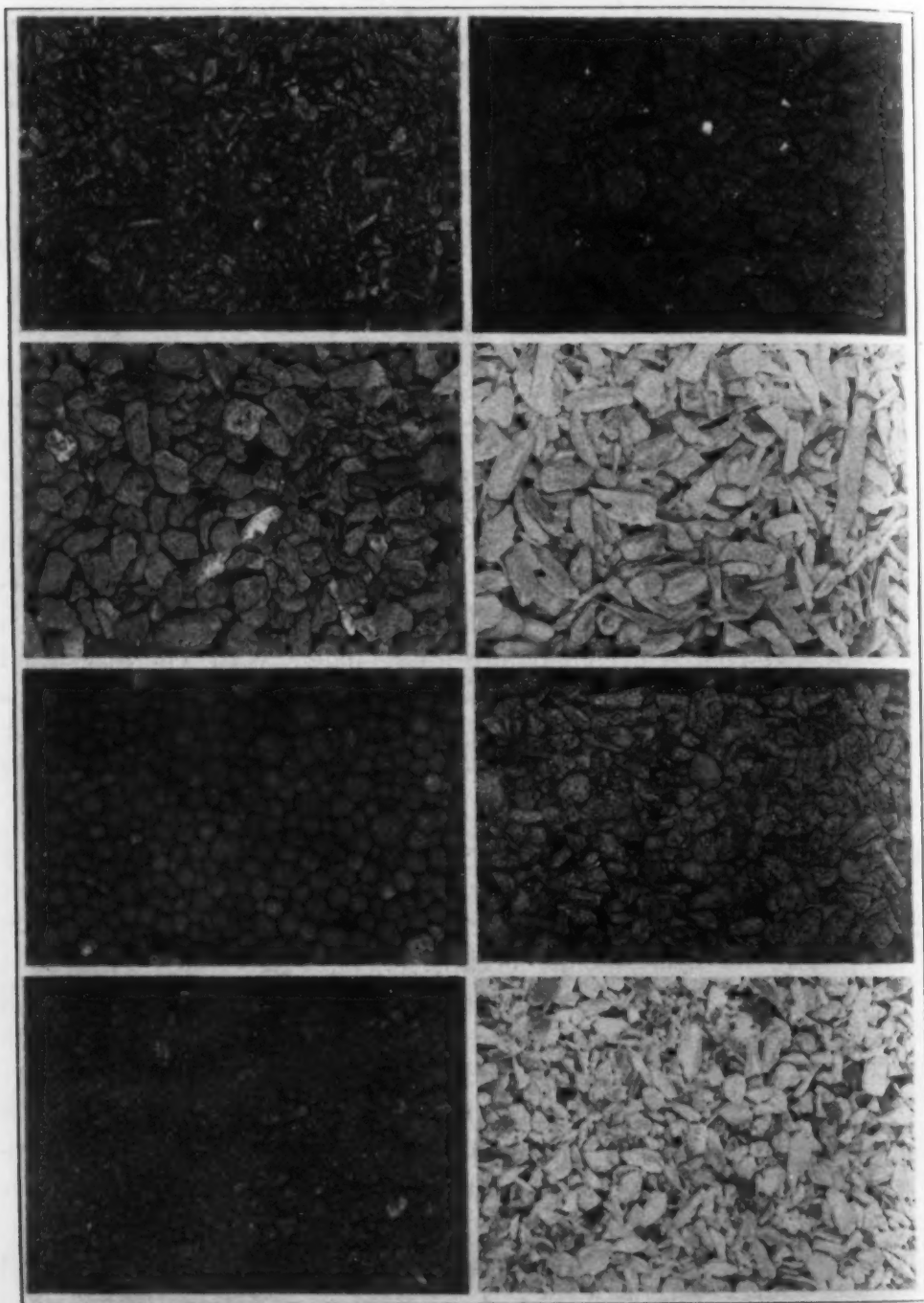


Fig. 3—Photograph of the Eight Different Commercial Carburizing Materials Used in this Test.

the work being exposed by the shrinkage of the compound, as the shop mixture usually is composed of several parts old compound to one of new. The packer may find he has used up all of his shop mixture and in order to fill the last few boxes may use all new compound, placing the same quantity of pieces in each box. Some of these will be exposed by the shrinkage of compound having a high initial shrinkage. In such cases, the top layer of parts should not be placed in the box and plenty of excess compounds should be used. This high shrinkage also adds to the cost of the compound.

#### COMPOUNDS USED IN TEST

The compounds used in this test are shown in Fig. 3. A compound should be reasonably free from dust. Dusty compound is disagreeable to the workman, causes a high compound loss cost and has a tendency to choke the compound, by keeping the gases away from the work. If the dust is composed of energizer it will settle to the bottom. The compound should not pit the steel. Some compounds are so heavily charged with energizer that a chemical action takes place between it and the steel and the finish of the latter is damaged. This condition took place with compound "C" and would prove exceptionally objectionable if this compound were used for pack hardening.

It might be mentioned at this time that a desired quality in a carburizing material is good thermal conductivity. In general, these materials are poor heat conductors, and the time taken to heat to temperature is a large proportion of the total time used in the production of thin cases. Some compounds absorb heat at certain temperatures to complete internal reactions. Raw bone contains a high percentage of moisture and volatile matter which must be driven off when first heated. Bone used once heats much faster than new bone and the desired case can be obtained in a shorter total time. Some compounds are impregnated with oil and a considerable amount of heat is required at 500-600 degrees Fahr. to volatilize the oil. At these temperatures, the hydrocarbon gases evolved are not of carburizing value.

#### DETERMINATION OF CARBON CONTENT OF CASE

In order to determine the carbon content of the carburized zone, the test pieces were placed in a lathe, the surface polished

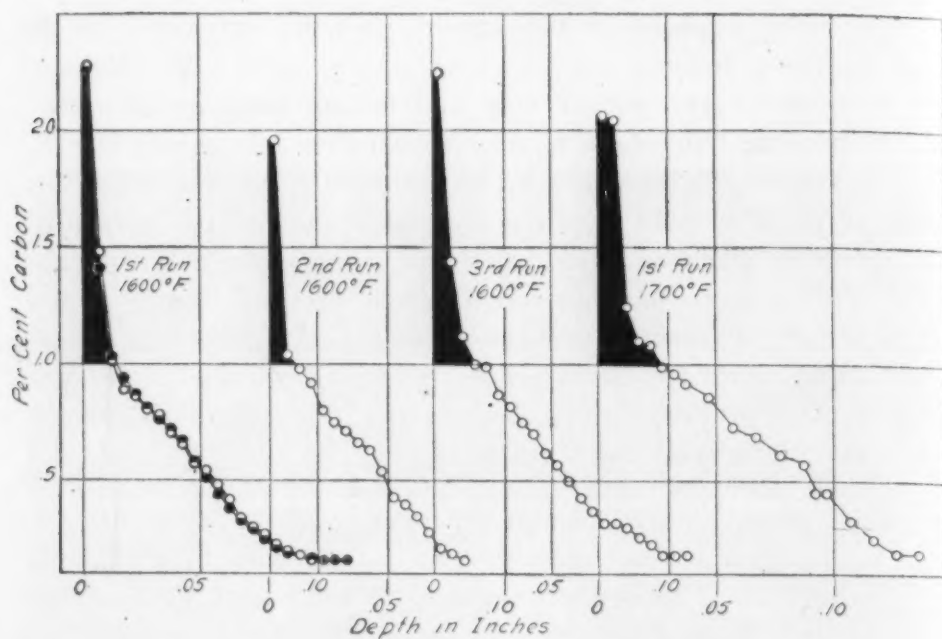


Fig. 4—Curves Showing Carbon Penetration of Compound "C".

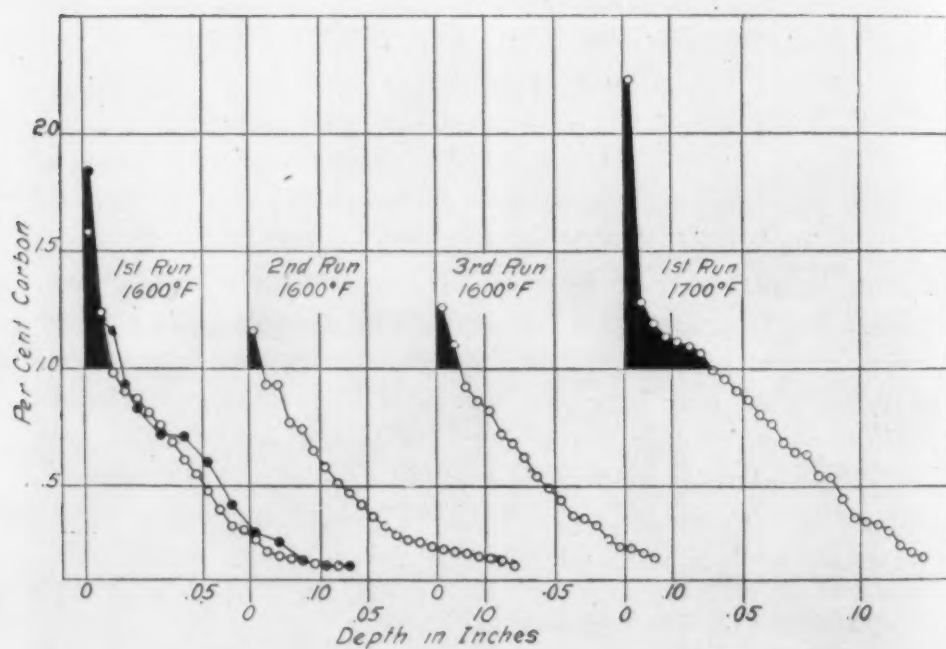


Fig. 5—Curves Showing Carbon Penetration of Compound "Q".

with fine emery paper and all traces of foreign material removed, the corners were cut back  $\frac{1}{4}$  of an inch to remove the increased depth of case at these regions and cuts of 0.005 inches thick by 4 inches long were removed with a high-speed steel tool. The chips were mixed and analyzed for carbon by the standard combustion method. It was necessary to use extreme care in removing the outer layers on the chrome-vanadium steel as the combination of the high carbon with the alloys present had made these regions self hardening upon slow cooling. Many of the determinations plotted are averages of several check analyses.

#### EFFECT OF CONTINUED USE OF COMPOUNDS

The different carburizing compounds shown in Fig. 3, were used in three separate runs, the time being 24 hours for each run at 1600 degrees Fahr. New compound was used for the first run and no new compound was added. A subsequent test was run at 1700 degrees Fahr. for 24 hours at temperature using new compound. The steel in each case was chrome-vanadium, S. A. E. 6120. The individual curves plotted from each run are shown in the accompanying diagrams.

The curve for the first run of compound "C," Fig. 4, is composed of the separate analysis of two samples which were in the box. This shows the uniformity of the specimens packed in the same box. The extremely high carbon content in the hyper-eutectoid zone is characteristic of the results obtained with each material. In each of the accompanying curves the zone above 1.00 per cent carbon is blackened for easier identification. The increase in depth of this zone on increase of temperature to 1700 degrees Fahr. is also noticable. It is seen that continued use of this compound does not effect appreciably the percentage and depth of carbon over 1.00 per cent produced in the hyper-eutectoid zone.

The carbon penetration results obtained in using compounds Q, W, S, A, B, and R are shown in Figs. 5, 6, 7, 8, 9, and 10. The summary of the results are shown in Fig. 11.

Compound S, Fig. 7, second run at 1600 degrees Fahr. actually has caused a decarburization of the specimen.

The curves, Fig. 8, show the results obtained in using compound A, and S. A. E. 6120 steel. While duplicate specimens

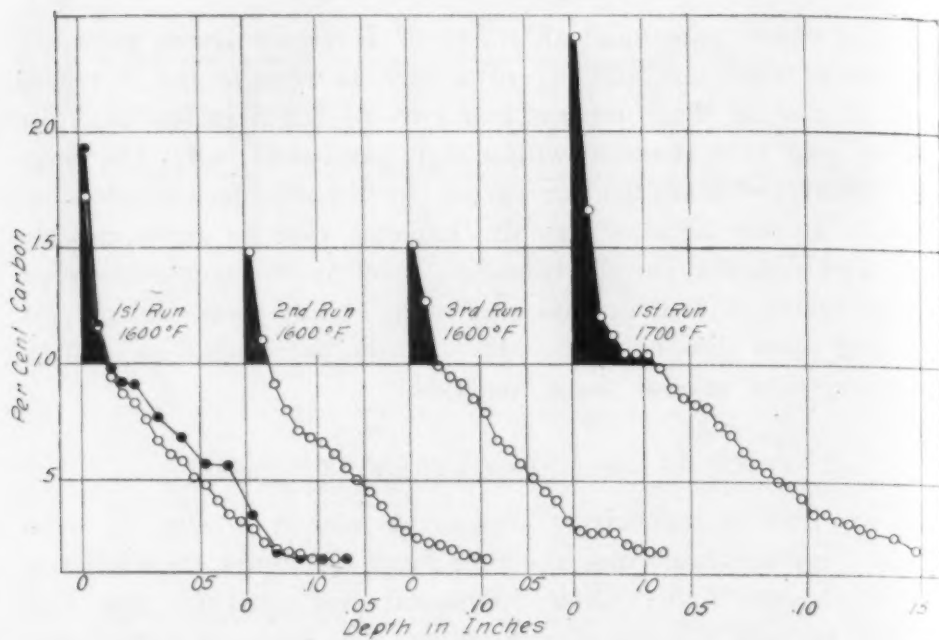


Fig. 6—Curves Showing Carbon Penetration of Compound "W".

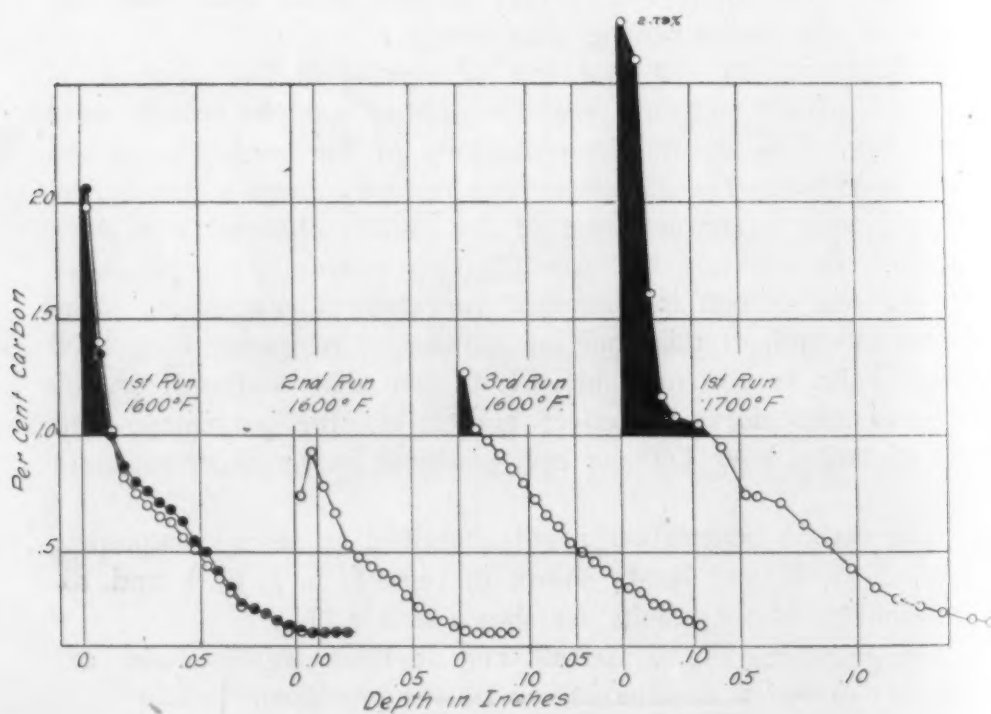


Fig. 7—Curves Showing Carbon Penetration of Compound "S".

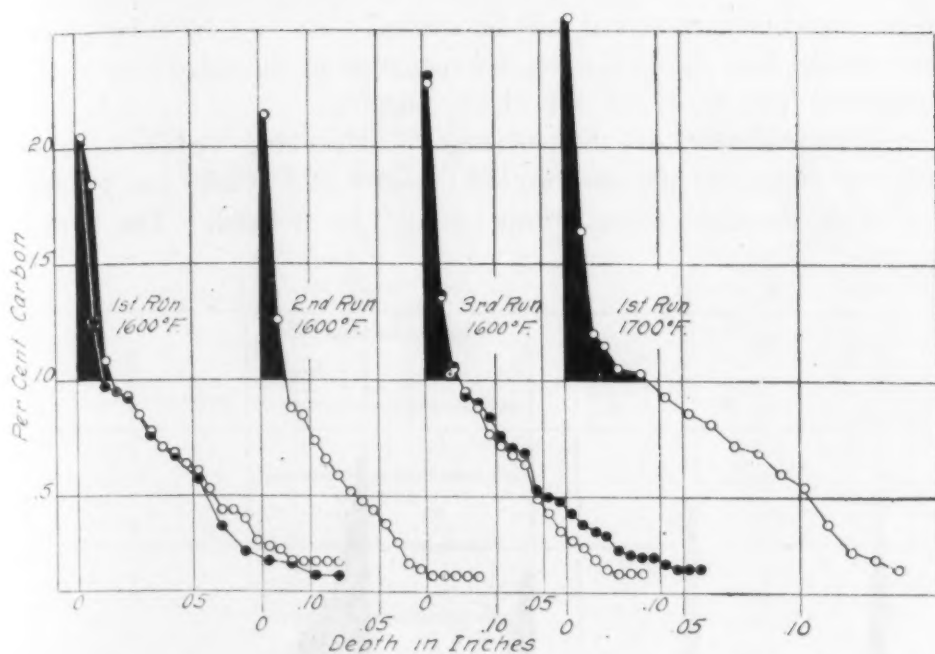


Fig. 8—Curves Showing Carbon Penetration of Compound "A".

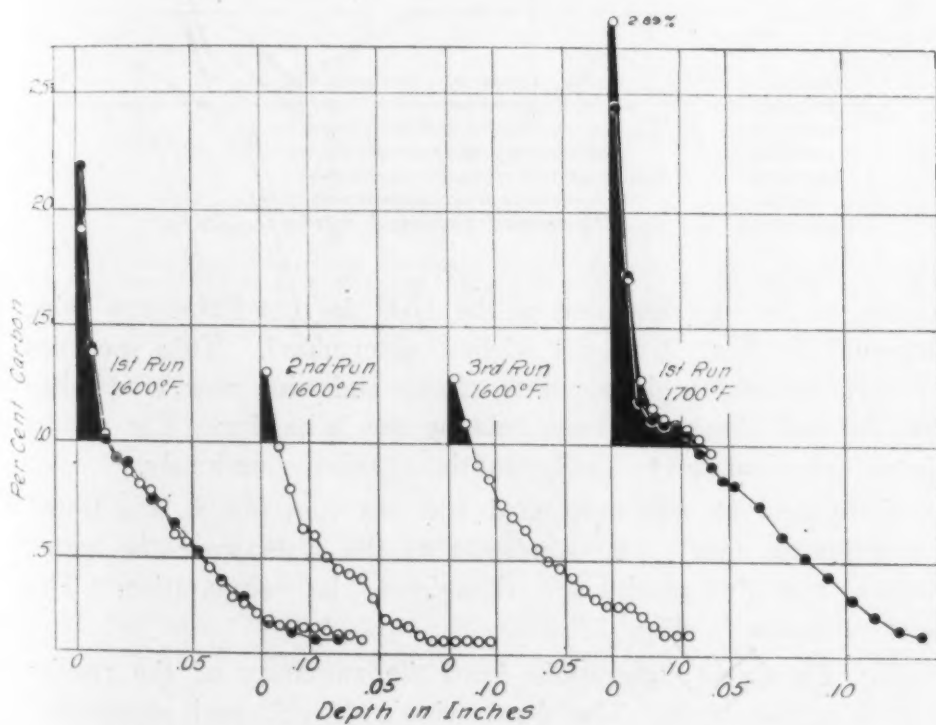


Fig. 9—Curves Showing Carbon Penetration of Compound "B".

were placed in each box it will be noticed that they have been used only on the first run. The second specimen in the third run of this compound was analyzed for check purposes.

The tendency of the increased carburizing temperature to build up carbon in the exterior of the case and render the graduation with the core more abrupt should be noticed. The carbon

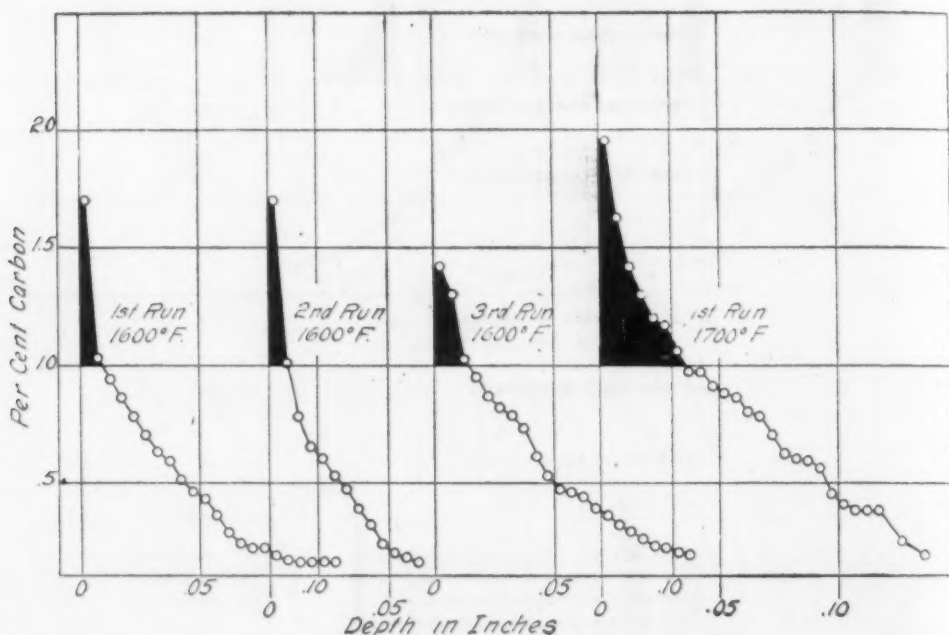


Fig. 10—Curves Showing Carbon Penetration of Compound "R".

analysis on the exterior zone of the 1700 degrees Fahr. run using compound B, Fig. 9, is the highest determined. This specimen was reversed and replaced in the lathe and nine new cuts taken from the end which had been held by the lathe dog. The results obtained checked very closely to those taken previously.

Compound H was only used for one run, but it was tested at a different time. The condition of the tests were the same, however, and the results are thought to be comparative. The curve is shown in Fig. 12.

Fig. 11, shows in graphic form the summary of the results obtained in the tests. The depth obtained with each compound together with average depth obtained on the three runs is shown.

The increase in the depth of the case and the depth of the region containing over 1.00 per cent carbon is readily seen.

### CARBON AND ALLOY STEEL PENETRATION

The effect of variation in time in this characteristic together with effect upon depth of case is seen on the test of a simple car-

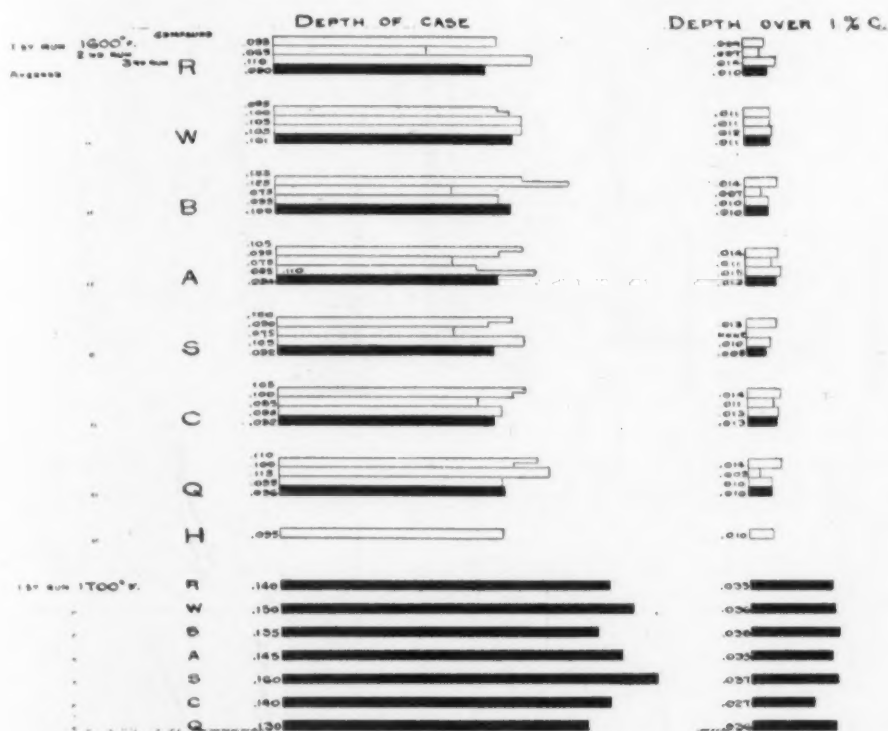


Fig. 11—Graphic Summary of Results Obtained in Figs. 4-10. The Depth of Penetration Obtained with Each Compound Together with the Average Depth Obtained on Three Runs is Shown.

bon steel, S. A. E. 1015 and a chrome-vanadium, S. A. E. 6120, Fig. 12. These curves were made with compound H at 1600 degrees Fahr. The effect of increased time at temperature, is to increase the depth of case and concentration of carbon over 1.00 per cent carbon in the chrome-vanadium steel; carbon steel in the same proportions. The carbon steel is not, however, subject to excessive concentration of carbon in the hyper-eutectoid zone and does not absorb carbon as readily as the alloy steel.

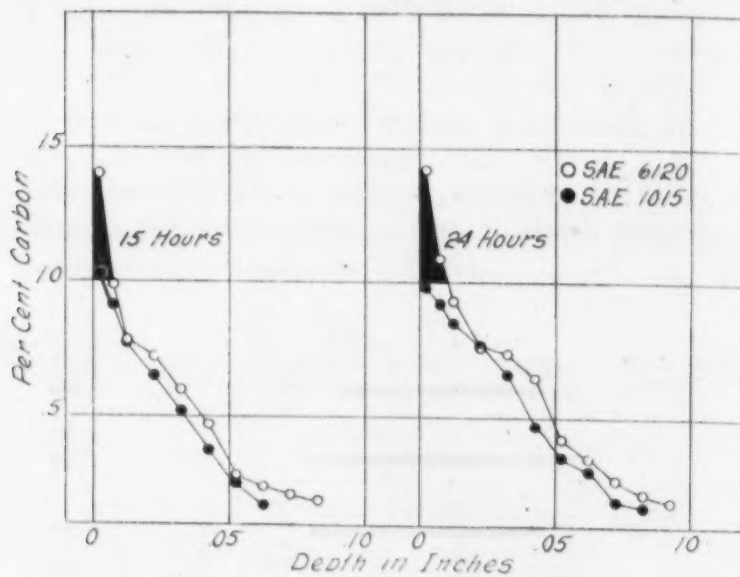


Fig. 12—Curves Showing Carbon Penetration of Compound "H".

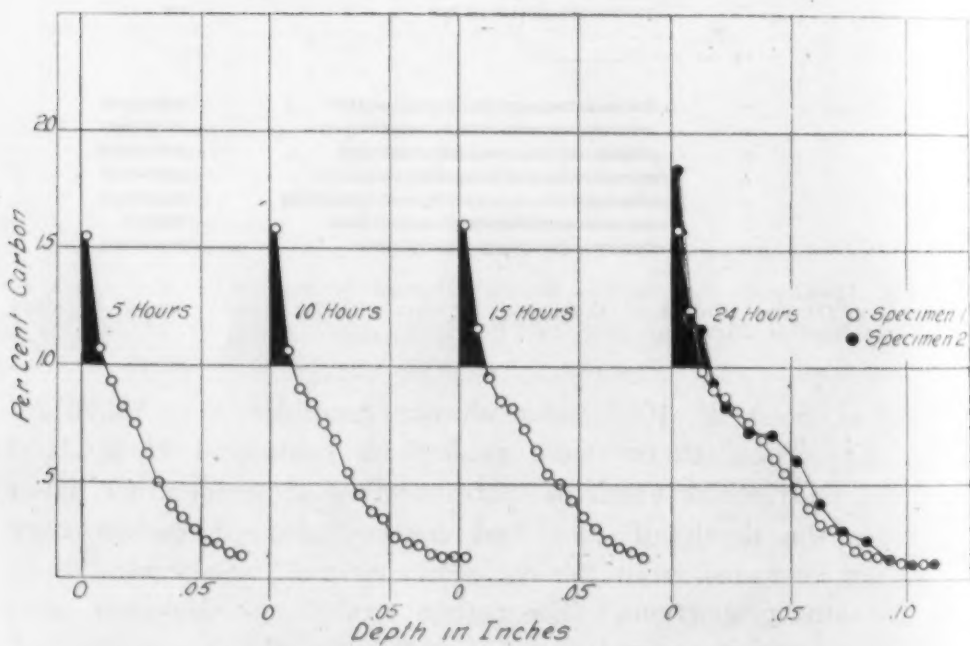


Fig. 13—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1600 Degrees Fahr.

## EFFECT OF TIME AND TEMPERATURE UPON DEPTH OF CASE USING SHOP MIXTURES OF COMPOUNDS

The effect of temperature of carburization is to increase the depth of case and the depth of excess carbon in the exterior zones. The curves in Figs. 13, 14, 15 and 16 were obtained with a shop mixture, 3 parts old to 1 part new compound, on a chrome-

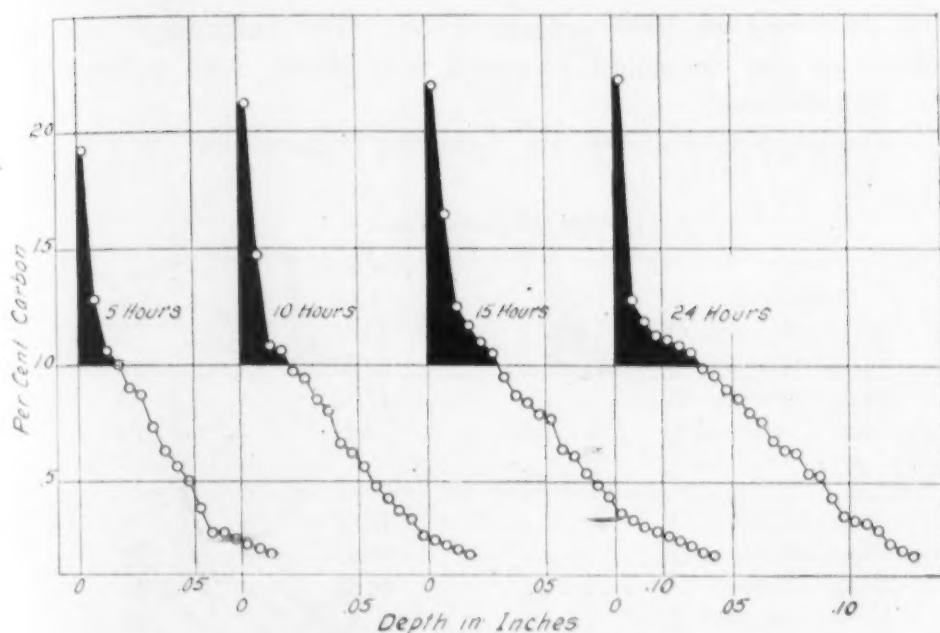


Fig. 14—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1700 Degrees Fahr.

vanadium steel S. A. E. 6120 at carburizing temperatures of 1600, 1700 and 1800 degrees Fahr. The compound used was "Q." The time given in all cases is after the box was heated through at the carburizing temperature. The 24 hour run at 1600 and 1700 degrees Fahr. were taken from the previous data and were made with new compound. Fig. 13, shows the results obtained at 1600 degrees Fahr., Fig. 14 at 1700 degrees Fahr. and Fig. 15 at 1800 degrees Fahr.

Fig. 16, is a general curve compiled from Figs. 13, 14 and 15, which shows this steel to have a tendency toward the 'critical penetration' described by Bullens and seems to show that carbon is absorbed slowly and gradually at low temperatures. An increase

in temperature tends to force carbon into the steel very quickly. A certain period of time, which is shorter than the higher carburizing temperature, is finally reached where the diffusion of the carbon into the interior proceeds more slowly with consequent slowing up of the penetration obtained with a given time and increase in percentage of carbon in the exterior zones.

The same depth of case was obtained with 3 hours at 1800 degrees Fahr. as was obtained with 10 hours at 1700 degrees Fahr. and 24 hours at 1600 degrees Fahr. The percentage loss in volume of the compound increased very slowly with increase in the temperatures.

The compound showed the following volume loss:

1600 Degrees Fahr.		
Compound	Per cent Loss	Time in Hours
Shop Mixture Q .....	16.67	5
Shop Mixture Q .....	17.83	10
Shop Mixture Q .....	17.83	15
New Compound Q .....	8.3	24
1700 Degrees Fahr.		
Shop Mixture Q .....	16.67	5
Shop Mixture Q .....	16.67	10
Shop Mixture Q .....	16.67	15
New Compound Q .....	19.8	24
1800 Degrees Fahr.		
Shop Mixture Q .....	17.86	3
Shop Mixture Q .....	18.75	6
Shop Mixture Q .....	17.83	10

The tendency toward high carbon content near the surface is not entirely confined to chrome-vanadium steel. Fig. 17, shows the case produced with solid carburizer on a chrome-nickel steel S. A. E. 3320, 15 hours after being heated through at 1650 degrees Fahr. cooling in the box (this box being larger than that previously used, the dimensions being  $9\frac{1}{2} \times 18 \times 23$  inches). By reference to the previous curves it is seen that the depth and character of the case produced are practically the same.

It might be noted at this time that the type of steel has a great influence upon the manner of distribution of the free carbides

in the hyper-eutectoid zone. In chrome-vanadium steels the carbide forms in tiny globules and spheroids, Fig. 18.

Simple carbon, nickel, and high-nickel low-chromium steels have a tendency to precipitate the carbide in the form of a network or needles unless the concentration is very high, Fig.

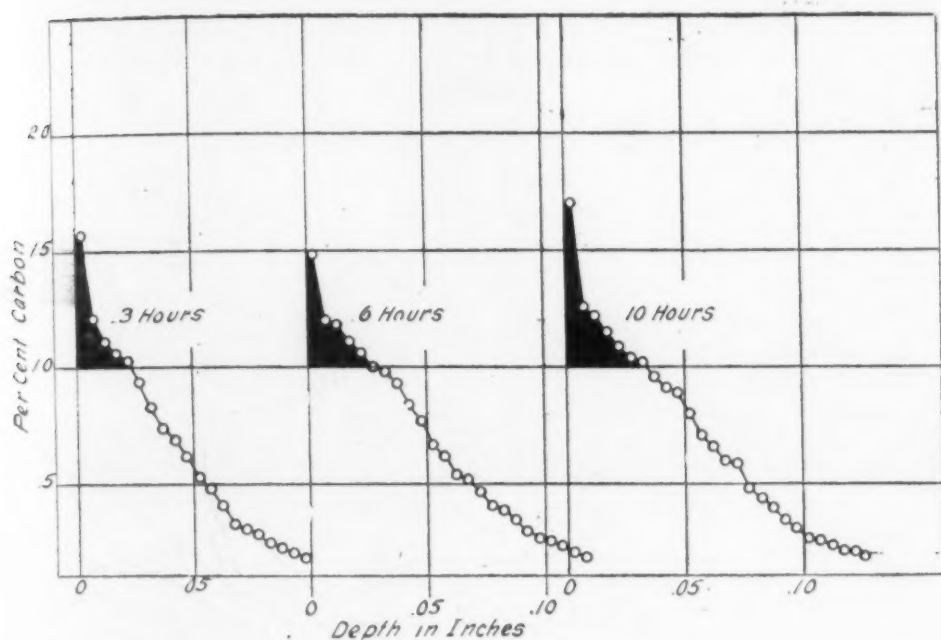


Fig. 15—Curves Showing Carbon Penetration of Three Parts Old and One Part New Compound "Q" on S. A. E. 6120 Steel at 1800 Degrees Fahr.

19. An excessive depth of high carbon gives rise to a fracture which has a fiery ridge or rim of very crystalline material.

Fluctuations or variations in temperature cause an excess amount of carbide to desposit near the surface. This is due to the fact that a slight drop in temperature causes the steel to become supersaturated with carbide precipitating some of the carbides. As the temperature again rises, the steel absorbs carbon from the carburizing gas much quicker than it can redissolve the carbide which it has just precipitated. When this occurs, an excess of carbide is found near the surface.

This phenomenon is seen very often in nickel and chrome-nickel steels. If the concentration is comparatively high, the box will cool much more rapidly than the steel can diffuse the high carbon into the interior and an excessive carbon concentration

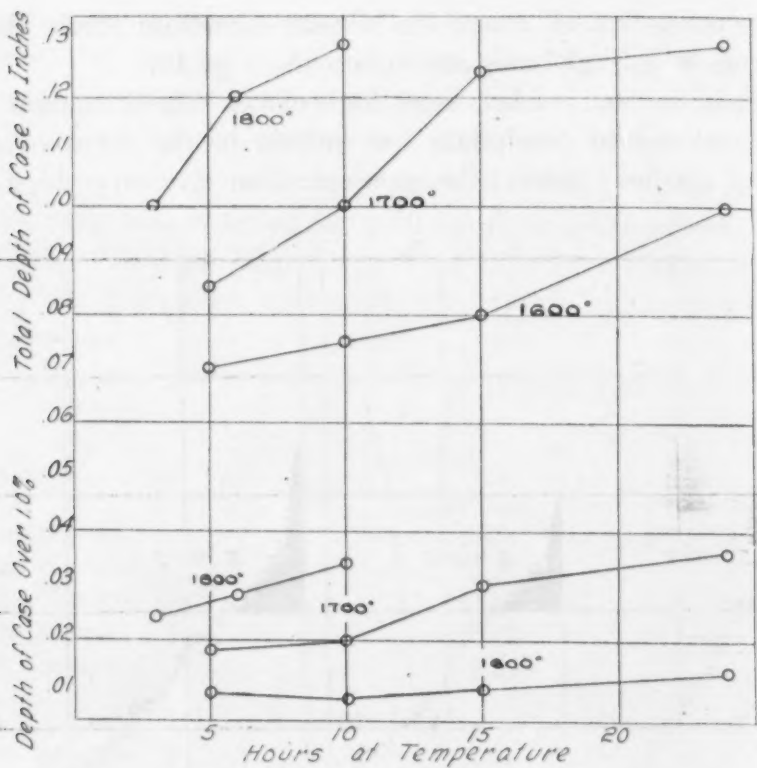


Fig. 16—General Curve Compiled from Figs. 13, 14 and 15.

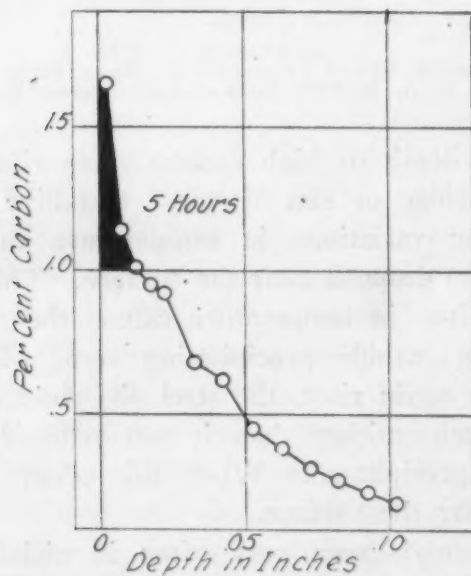


Fig. 17—Shows the Case Produced with Solid Carburizers on a Chrome-Nickel S. A. E. 3320 Steel, 15 Hours after being Heated Through at 1650 Degrees Fahr.

on the outside is the result. This discontinuity gives rise to a fracture which has a fiery edge or a thin border or rim of very crystalline material. This rim is composed almost entirely of carbide which is the hardest constituent in steel. It cannot be

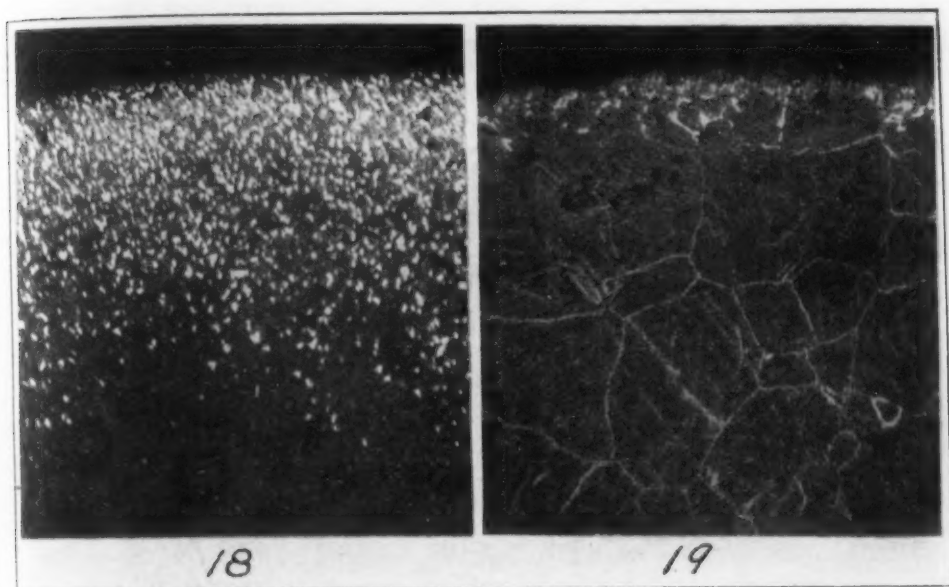


Fig. 18—Photomicrograph of Chrome-Vanadium Steel Showing a Concentration of Tiny Globules Near Surface. Fig. 19—Photomicrograph Showing Net-work of Carbides Near Surface of Carburized Chrome-Nickel Steel.

softened by tempering and is very brittle. Fig. 19, shows this type of zone on a chrome-nickel steel.

Cases of this type are subject to enfoliation or splitting off under shock, local heating caused by grinding, quick tempering or heating for hardening, etc. The face breaks off in flakes on a line parallel to the surface corresponding to the line of separation of the high carbon and eutectoid zone. The high carbon zone cannot deform on account of its intrinsic hardness and rigidity. Liquation is the term used for the separation of the normal and high carbon zone. Enfoliation is the term used to splitting off of the high carbon area formed by this separation.

The micrographs shown by S. C. Spalding in his paper published in the August 1922 issue of *TRANSACTIONS*, illustrates the tendency of the excess carbides to assume a form which is peculiar to the type of steel.

## INSPECTION OF FINISHED PARTS

The best method of determining the ability of a carburized part to withstand service is to place it in actual service. After finding a type of steel which treated in a definite manner will give satisfactory service, the next step is to reproduce that part. The best method of testing the carburizing operation is to examine

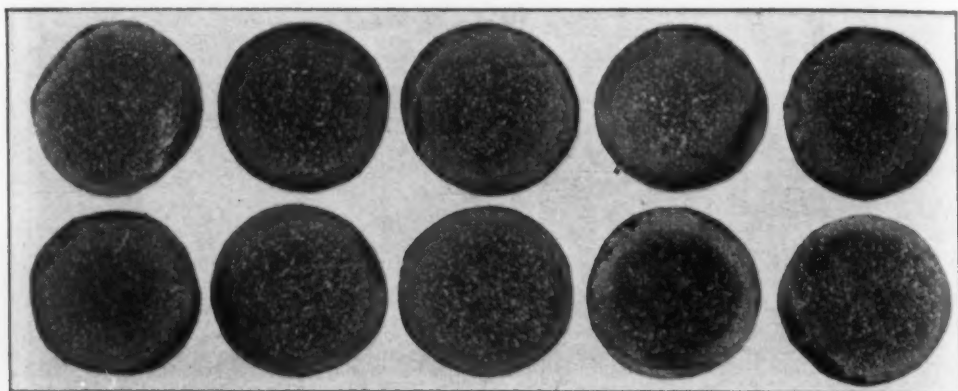


Fig. 20—Typical Fractures of Carburized Specimens of Steel.  $\times 1\frac{1}{2}$ .

the case after subjecting the part to the standard heat treatment. This examination may be made by breaking the part for fracture or by taking sections from it and examining them under the microscope. The fracture test is easily made a routine inspection and gives a constant check on the quality of the material leaving the heat treating department. Fig. 20 shows some typical fractures.

Examination of the fracture should show whether the case is sufficiently deep, or the case and core are well refined. It is well to adopt a definite standard of depth which should be noted on the heat treatment instruction card. The method of breaking for fracture, gradually or quickly, across or with the grain alters the fracture and apparent depth of case considerably. Before rejecting a part on account of insufficient depth of case it should be broken several times.

The microscope is used as a supplementary means of inspection on special work. It is a matter of a few minutes for

the metallographist to polish, etch and examine a specimen for depth of case, distribution of carbon, etc.

The scleroscope and file are a means of testing the surface hardness. The scleroscope gives comparative results on the same material. The file hardness depends entirely upon the character

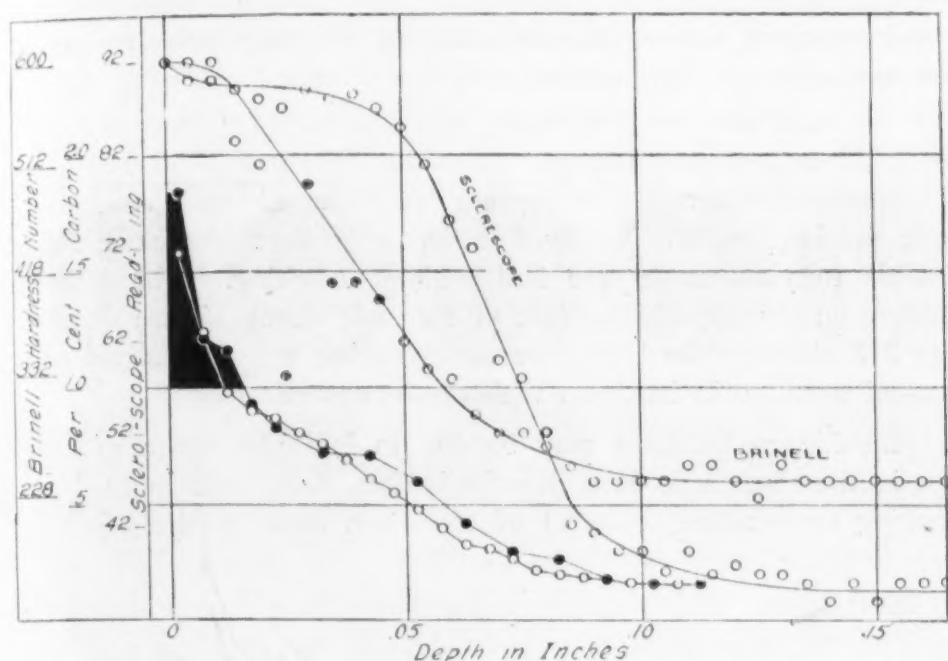


Fig. 21—Curves Showing the Relationship Between Scleroscope Hardness, Carbon Content and Penetrability Using Compound "Q".

and uniformity of the files used and the method of testing. The Brinell method is objectionable as it punches through thin cases and gives incorrect readings. Some plants use a pointed hammer to test the case. If a blow with the hammer does not cause fracture the case is assumed to be satisfactory.

### HARDNESS

A slab about  $\frac{7}{8}$  inches thick was cut from a 2-inch round bar 5 inches long, of chrome-vanadium S. A. E. 6120 steel which had been carburized for 24 hours at 1600 degrees, Fahr., reheated to 1625 degrees Fahr. and quenched in oil, reheated to 1470 degrees Fahr. and quenched in brine. The specimen was ground parallel to the end of the specimen upon which hardness readings

were taken with scleroscope and Brinell machines, halfway between the center and circumference. Layers 0.005 inches thick were removed and consecutive hardness readings taken.

It is interesting to note (Fig. 21) that the scleroscope hardness remained rather high until the carbon content of the case dropped below 0.50 per cent carbon. The carbon content of the hyper-eutectoid zone apparently had not had any influence upon the hardness.

The case resisted penetration by the Brinell ball until a depth of 0.025 inches was reached. Between this and 0.045 inches a continuous circular crack appeared outside of and concentric with the indentation. Under this depth the case was sufficiently flexible to yield under the ball without cracking. The Brinell number on the opposite surface of the slab, about  $\frac{7}{8}$ -inch distant, was 217 although the last consecutive reading was 241, showing a gradual decrease in hardness with depth was effected.

Insufficient hardness may be due to low percentage of carbon in the case, superficial decarburization, delay quenching, high drawing temperature, removal of too much stock in the grinding operation, etc.

Soft spots and insufficient hardness have been attributed lately to the presence of dissolved oxides in the steel. A material which hardens satisfactorily presents as carburized a 'normal' structure under the microscope while a steel which produces 'soft spots' has an 'abnormal' structure. The writer's experience has been that 'soft spots' have been a very infrequent cause of trouble and all cases which have occurred have been readily found due to some other factor than the steel.

Sudden cements have the tendency to push carbon in the steel much quicker than it can be diffused and produce high carbon cases particularly subject to enfoliation. It may be prevented by the use of cements which do not have such a violent action. Carburized parts must be heat treated so that they will give satisfactory service. The heat treatment must also be done economically or at the lowest cost consistent with good practice.

After being held the desired time at temperature, the grain of the case and core is large, due to the long soaking at high tem-

perature. If allowed to cool slowly, the excess carbide will form a network between the grains or separate in large masses. If quenched from a temperature which will harden the case, the carbide structure will not be changed and will form an easy path for fracture due to its intrinsic brittleness. Quenching in oil from the carburizing temperature where this excess carbide is in solution will precipitate it in extremely fine particles. It will not have time to separate between the grains. This quench also has a hardening effect upon the core. The disadvantages are that it does not have any refining action upon the coarse grain left by the long heating, that the proper quenching temperature for the core is below the usual carburizing temperature and that large work is difficult to handle on account of the heat.

The pieces should be allowed to cool in the box and reheated to a temperature which will refine the core and also break up any undesirable structures of cementite. This is called a regenerative quench because it regenerates or restores the core.

The parts are then reheated to a lower temperature and are quenched to refine the case. This temperature is lower than the critical temperature of the core and the grain size produced in the core by the previous quench is not affected. This final quench may be in oil or water according to the type of steel. Some steels have the critical points of the case lowered by alloys to such an extent that they become hard when quenched in oil. Other steels are non-machineable after cooling in the carburizing box, due to the same phenomenon.

The stresses in some parts should be relieved by drawing in oil to about 375 degrees Fahr. This will not have any effect upon the hardness but will increase the strength, toughness and uniformity of the product. Chrome-vanadium steels require a drawing temperature about 25 degrees Fahr. higher than other steels to cause them to lose their file hardness.

The heat treatment and method of handling is varied in the usual manner according to the shape, size and previous history of the piece. The best results can undoubtedly be obtained by allowing the piece to cool in the box, reheating it to a high temperature to regenerate the structure of the core, reheating to a lower temperature to harden the case, and drawing to relieve the internal stresses set up in these operations. Costs, however,

regulate practice and are of course subject to the service requirements of the part. In many cases a single quench from the carburizing temperature is sufficient. An improved quality of product with lower costs can be obtained by a careful study of the material, heat treatment and service conditions.

## TOOL ROOM TROUBLES

By A. H. Kingsbury

*Abstract*

*The author of this paper has reviewed in considerable detail the various factors involved in the production of hardened tools. He discusses the necessity of a careful study of the problem at hand inasmuch as the improper selection of steel is the most frequent cause of tool room troubles.*

*Of the numerous factors involved in the production of cutting tools, the author specifically discusses the marking of various grades of steel, design, machining strains, heat treating, the proper hardening range, quenching speeds, drawing, soft spots and similar troubles, vanadium as an alloying element and grinding practice.*

**R**EFERENCE to trouble is generally distasteful to most of us. The word is, however, directly a stepping stone to experience and knowledge, especially when we recognize and admit the existence of trouble and in each occurrence make a careful analysis of its causes. The tool room personnel and equipment is of major importance in a plant inasmuch as the magnitude of the success or failure of the enterprise is to a considerable degree dependent upon the manner in which this department functions. The present day demand for economy in production to offset the shortage of labor and progressively ascending wages, has given the ways and means of doing things in the tool room, a significance greater than heretofore.

The gradual approach to perfection in our engineering practices, and the demand for greater and greater accuracy, have taxed to the utmost the originality and initiative of the tool designer and tool maker. Thus, the work of tool making demands more than a good mechanic and accurate workman. In the past these characteristics qualified a man for the trade, but at present the complex demands of modern pro-

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A paper presented before the New York chapter of the Society. The author, A. H. Kingsbury, is associated with the Crucible Steel Co. of America, Atha Works, Harrison, N. J.

duction have raised it to the position of a fine art, in fact, an art upon which the ambitious and successful tool maker, designer, or treater may well look with considerable pride. Unfortunately all tool makers do not consider it in this light, and as a consequence fail to give their profession the careful study, the present situation demands. They fail to realize that constant evolution has, to a great extent, made the rule of thumb methods, instructions etc., of yesterday practically obsolete today, so that entirely new methods being in demand, the ambitious man will endeavor to gain that most necessary qualification for his work, namely, "originality." He may accomplish this by availing himself of some of the excellent and readily accessible sources of information in existence at the present time. The remarkable revolutionary period in engineering business, which started about twenty-five years ago is undoubtedly the direct result of publicity brought about by straightforward discussion.

As an example of this, let us consider the art of steel making. Not more than 20 years ago, the manufacture of tool and special steels was shrouded with a considerable degree of secrecy; each manufacturer had his own pet mixes, analyses and obscure methods of making his product. In fact his chief claim for consideration over his competitors was the carefully guarded obscurity of his entire process. The advent of the chemist and metallurgist along with the noteworthy progress made in their respective fields, has entirely dissipated the old order, and those subjects which previously were so jealously guarded, are openly discussed, and at the present time the steel maker bases his claim for consideration on the quality of his product as the result of research, knowledge, and care, which are the controlling factors in its manufacture. The writer wishes to emphasize his belief in the great benefit derived from these open discussions, for it seems to him that we must realize that the most abstract problems become simple in their solution when many minds are brought to bear on the subject. Thus, it naturally follows that the American Society for Steel Treating which was organized with the actuating purpose of discussing the complex problems confronting the worker in metals, is an organization of incalculable benefit to those who wish to avail themselves of not only a

technical but a highly practical education in the art of working and treating steel.

At times, unfortunately, the failure of tools is the fault of the steel and it is by the careful and thorough investigation of these failures, that the steel maker is progressively eliminating them. A personal observation points to the conclusion that in the instances where the blame rests on the steel, the majority of these cases are directly attributable to the "human equation."

Progress has been responsible for another and most encouraging change in the art of tool making. In the past, the trade was handed down from father to son and was really what might be termed a family affair. Like most things which are hereditary, the practice resulted in developments along narrow lines, and while it may have promoted a high degree of skill, it also resulted in an attitude both narrow and prejudiced. This condition has been subject to a radical change in that the tool maker at present is selected for his ability, regardless of what trade his ancestors followed. A man so developed is invariably open-minded and willing to discuss or listen to any subject which may be of benefit to him.

#### THE SELECTION OF THE STEEL

Possibly the most frequent cause of tool room troubles is primarily in the improper selection of the steel. In deciding this question to the best advantage, a careful consideration should be made of the work accomplished.

If the tool maker or designer does not have at least a working knowledge of the characteristics of the various tool and alloy steels available, or the proposition is one with which he is not thoroughly familiar, he can generally obtain the necessary information from the steel manufacturers, though in some instances the maker's experience will not allow him to state definitely just how the steel will perform under all conditions when it is in the finished tool. However, in making this choice the tool maker may find some assistance in the following questions:

1. What are the physical characteristics of the metal to be cut or otherwise worked by the tool? Is

it soft, hard, soft and tough, medium and tough, hard and tough, or will it have an abrasive action on the cutting edge of the tool?

2. Does the work planned necessitate an ordinary carbon, extra carbon, or alloy tool steel? Can initial hardness in the steel be sacrificed to gain toughness?

3. Does the class of work demand a deep hardening steel? Is there danger of the tool sinking and consequently cracking under pressure, when made from a shallow hardening steel?

4. How much size change is permissible in hardening?

5. At what speeds will the steel be required to work?

In answer to questions 1 and 2 for soft materials where toughness is not a factor, a hard steel should be used, and while most of this class of work can be satisfactorily accomplished by using a carbon steel, tungsten tool steels will generally give much longer service. For hard steel the same is true, but the difference between the length of service obtained by using one of the tungsten steels is much greater than where soft material is to be cut. For soft and tough cutting, a softer but tougher tool steel will show up to advantage though a harder steel may be used to a better advantage, if the drawing is sufficient to produce the maximum toughness obtainable with the necessary hardness. For hard and tough steels, alloy tools work to the best advantage, particularly the tungsten or chromium-tungsten steels, which develop a very hard close grain. This condition naturally enables them to resist wear and abrasion better than a steel which does not have this characteristic developed to the same degree. It is not intended to imply that good carbon steels will not be suitable for any or all of these classes of work, but the fact is emphasized that tungsten tool steels will work to advantage, and in the majority of cases give much longer service than those steels which do not contain this element. In answer to question 3 it has been found that for most tools which have to withstand heavy pressures, such as dies, punches, etc., a deep hardening steel is recommended particularly for

those where the metal to be worked is dense in nature, or hard. A carbon steel, except in small sections will not harden deeply, so the use of an alloy steel is preferable. In addition to their deep hardening characteristics these alloy steels, either chromium, chrome-vanadium or chrome-tungsten, resist wearing action and abrasion. The oil-hardening nondeforming steels harden deeply and for many classes of punch and die work these steels are being used with a great degree of success. Another advantage gained by using this type of steel is that they do not change size in hardening. They do not attain, however, the intense hardness of some of the other alloy steels, and as a consequence can be used to better advantage on the softer classes of work.

The steels containing 2 to 7 per cent tungsten are capable of remarkable abrasion resisting qualities and their use is an economy for finishing tools on automatic machines for most classes of work. Their dense close grain will enable them to cut the hardest materials, but not at high speeds. The fact that a steel contains tungsten does not necessarily make it a high-speed steel, neither does it follow that the presence of this element will allow the tool to cut at much higher speeds than ordinary carbon steels, though the tungsten steels will last much longer on most of the materials at the same or slightly higher speeds and they will cut materials upon which carbon steels will not even start. Thus, the chief advantage of the tungsten over the carbon steels is longer service between grindings, a better finish due to their intense hardness, close grain, and their ability to cut materials which are too hard for carbon steels and at times impossible to cut with the standard high-speed steels. Due to their much wider hardening range, the hazard of loss by overheating in hardening is much reduced.

One frequently hears nearly all classes of tungsten steels referred to as semihigh-speed steels, but this terminology, the writer is convinced, is misleading. The fact that the so-called tungsten tool steels, such as those containing from 1 to 7 per cent tungsten, have their hardness breaking-down points but slightly higher than carbon steels and much below that of both the old self-hardening and modern high-

speed steels, would indicate the term "semihigh-speed" should be applied, if it is really necessary to apply it at all, to the almost obsolete self-hardening steel whose hardness breaking-down point is about 300 degrees higher than that for the carbon or tungsten steels and approximately 400 degrees below that of the modern high-speed steels. Therefore, if on using a carbon or tungsten steel at what might be thought to be sufficiently low speeds, the tool does not stand up and it is known that the proper conditions have been met in the treatment, do not jump at the conclusion that the tool has not been softened under the frictional heat of the chip simply because the edge does not show color or the softness cannot be felt with the file. Reduce either the speed or adopt a high-speed steel for the purpose and increase the speed, for as a rule, high-speed steels work to a disadvantage at carbon steel speeds.

From the foregoing it can be seen that the writer is particularly interested in tungsten steels, and he feels that an explanation as to his attitude is in order. Considerable time spent in research on the influence of tungsten in steel has indicated that it is a most fascinating field for investigation and has influenced him to form some theories and then search the literature for the purpose of confirming or contradicting them. While this search has to date been successful in uncovering a few technical articles by English and German authorities, there seems to be a dearth of papers either practical or technical on the subject by American authors. The careful perusal of those discussions that could be found on the subject of tungsten steels, with a personal investigation of some of their properties, have convinced the writer that this steel as a class, has been sadly neglected, and its thorough investigation in both a scientific and a practical manner by our modern metallurgists and tool makers will open up a very wide field of usefulness. Suffice it to say, that there is no doubt whatever, that these steels have latent possibilities which have been practically unexplored up to the present time, and careful and thorough research will, without a doubt, be repaid in concrete results. For this discussion the steels referred to as "tungsten steels" are those which contain tungsten in excess of 1 per cent and do not come in the high-speed or "self hardening" steel classes.

### VANADIUM AS AN ALLOYING ELEMENT

Vanadium as an alloying element is very active in changing the properties of steel. In fact, it is so active that its addition to the extent of even 0.15 per cent makes the steel to which it is added an alloy steel, while any of the other alloying metals have to be present in appreciably greater quantities to place the steel in the alloy class. The addition of vanadium in correct proportions to a carbon steel, adds several valuable properties, such as an increased hardness and toughness, both of which augment to a great extent the life of the tool. It also adds several other properties to steels which however, are of no direct bearing on the subject so will not be discussed.

The acknowledged superiority of the vanadium-carbon steels over the straight carbon steels in durability is no doubt due largely to the fact that vanadium resists the formation of lamellar pearlite and in hyper-eutectoid steels massive cementite, thus acting to give the annealed steel a finely spheroidized structure which is the ideal structure for tools. In addition to increased hardness and toughness, vanadium also acts like chromium in increasing the depth of hardness.

### PROPER HARDENING RANGE

Another condition which has frequently caused trouble is heating a carbon steel beyond the proper hardening range to gain a greater depth of hardness, for while this practice will result in a harder core, the hard surface is correspondingly weakened by coarsening the grain, and the service from the punch or die, is thereby sacrificed. When it is found necessary to prevent sinking because of a soft core, a deep hardening steel such as a chromium or chrome-nickel, nondeforming or high-speed, should be used. In fact, when any serious doubt exists as to just what steel to use it is generally a safe bet to try high-speed steel which, with our present knowledge of the elasticity of the treatment of this type, makes it suitable for almost any kind of tool.

For a precision tool the nondeforming oil-hardening types of steel are obviously the best. The size change, however, in either a carbon, tungsten or chromium steel can be greatly reduced by roughing it out, oil hardening it at from 50 to 75

degrees Fahr., above the temperature at which it would ordinarily be quenched, and either draw or anneal it just sufficiently to allow it to be finished up, then apply the regular treatment. This makeshift should never be resorted to unless a nonchangeable steel is not available or suitable for the work.

#### MARKING GRADES OF STEEL

As all tool rooms use more than one kind of steel, a method of keeping the various classes of steel separated must be adopted. The system of symbolizing the various kinds of steels should be such that the short and smallest pieces can be easily identified. Different colored paints and numbers or letters stamped on the bars or pieces are the best means of preventing mixups. If when the bar of steel is received it is immediately painted with a stripe the length of the bar, stamped, lettered or painted, a distinctive number, letter or color on each end, it can be easily identified at any time. Failure to do this may result in the loss of some very expensive tools.

#### DESIGN

The design of the tool is one of the most important features, as it relates to the cutting angles and many other elements which are large factors in the ultimate results obtained. The importance of proper lip angles is so well known that it seems unnecessary at this time to dwell upon this essential feature. The tool designer should consult with the hardener and in any event should understand the fundamental principles of hardening. Sharp corners, adjacent thick and thin sections are potential causes of cracks and spalling and should be avoided when possible. If not possible and the tool is to be an expensive one, use an oil hardening or high-speed steel.

Some tools, regardless of how carefully they are treated, will warp and this point is where the good hardener can be of assistance to the designer, for he can advise him where the warpage is likely to occur and thus provision can be made for grinding. If the tool is such that it cannot be ground subsequent to hardening, the safest procedure is to use a nondeforming or nonchangeable oil-hardening tool steel.

All hot rolled or hammered steels are likely to have a

more or less decarburized surface, so it is poor economy to buy the steel too close to the finished size, as sufficient material should always be allowed to insure the complete removal of the decarburized surface.

In designing punches and dies, the proper clearance is of basic importance. It is difficult to establish hard and fast rules to cover this point due to the action of the various metals which may be fabricated by the tool. However, a safe rule which can generally be followed is to allow clearance equal to about 1/6th of the thickness of the metal to be punched. For hard metals this ratio can be reduced to as much as 1/12th. When punches break, a good practice is always to start with the investigation of the clearance, providing that the fracture of the tool does not indicate anything irregular in its physical properties.

#### HEAT TREATING

The subject of this paper would indeed be but poorly dealt with if due consideration were not given that most essential adjunct to the tool room, namely the heat treating department, for it is here that a majority of tool room troubles have their origin. In considering this phase of the subject, the writer will necessarily have to present it in a general and not a detailed manner, for were it to be dealt with in detail, and in justifiable way, this meeting would have to assume the proportions of a convention.

The use of a pyrometer is strongly recommended as it is of valuable assistance in duplicating results. An instrument, however, which does not have the necessary attention and is not checked for accuracy from time to time is obviously of negative value and the source of trouble. Fortunately the present product of the pyrometer makers is as near fool proof as they can possibly make it, but they are not perpetual motion machines and consequently need a little of the human touch now and then, to keep them in condition.

Where it is possible, an instrument should be kept for checking purposes, but where this is not practical, service can be had at any time from the maker, for a very nominal charge. The instrument is of assistance to, but cannot take the place of

the intelligent hardener and therefore its introduction should not lead to the conclusion that hardening troubles are at an end. It will measure the degree of heat in the particular section of the furnace where the hot junction is located, but sometimes furnaces do not heat uniformly. Consequently, unless the furnace heats uniformly and the operator knows how to use the instrument, either the steel, the pyrometer, or both, are placed in a very disadvantageous position. The pyrometer helps to regulate the "human element" but neither it nor any other instrument designed to date can eliminate the hardener, who should have just as much if not more, skill and judgment than his predecessors of years gone by when steel was hardened by the eye, and the hardener was considered a specialist.

In addition to the pyrometer and the hardener, the proper furnaces and hardening room equipment are necessary if trouble is to be avoided. As details of the equipment have to be suited to the peculiar requirements of the individual shop it is impossible to consider them in any more than a fundamental way in this discussion. The furnaces should be so designed that they will be of ample size for the work, and capable of maintaining a uniform temperature throughout. The fuel supply, the valves, drafts, etc. should be such that the atmosphere of the furnace can be kept either neutral or reducing at all times. If precision and delicate tools are to be treated, one or more preheating furnaces are of great assistance.

A brine of water tank or both and a suitable oil quenching system of sufficient size are necessary. The water and brine cooling tanks should be so designed that the temperature of the quench can be kept below 70 degrees Fahr. A good thin quenching oil is easily obtainable. Either furnaces, oil baths or some other means should be provided for drawing and as a necessary adjunct to them a suitable means for accurately determining their temperature, though tempering by color, if it is thoroughly understood will be suitable for some classes of work. It must be remembered however that temper colors do not appear below 420 degrees Fahr. and this is too high for many tools; thus to get accurate results, a furnace or bath with a temperature indicator is good and in the long run, an economical investment.

Cracking, spalling and warping are the direct results of

strain. Nonuniform heating and cooling conditions are by far the causes of the greatest majority of these troubles. Thus by a careful and thoughtful consideration of the conditions from which strains originate, many of the troubles incident to hardening can be eliminated. It is admitted that the design to which some tools have to be made will invariably produce warping. A proper attention to the heating and quenching as well as to the selection of the steel can reduce this condition to a point where it is almost negligible, and if necessary, the tools can be straightened at the drawing temperature.

All steel in the first operation (hardening) should be treated in such a manner as to give it the greatest possible hardness with the greatest refinement of the grain, and the proper hardness for the finished tool should be regulated by the degree to which it is drawn. In its initial hardened condition, the steel is under a tremendous strain particularly, if its design makes necessary adjacent thick and thin sections, sharp corners, etc. It is therefore obvious that this tension or strain should be relieved as soon as the quench has proceeded to the degree where maximum hardness is obtained. The exact point in the quench where this condition is reached is difficult if indeed possible to determine, but best practice and experience indicate that it is somewhat higher than the temperature of the quenching both, particularly if this be water or brine. If the quench is in oil, it should be used hot, generally from 80 to 150 degrees Fahr., for oil hardening steels, and as hot as possible for high-speed steels, so the careful attention to relieving strains at once, while it is not as essential as for the water or brine hardening steels, is good practice. A procedure which seems to be productive of good results is to continue the quench in water or brine, until the hand can just touch the piece and then finish cooling in either hot oil or draw the tool. This practice also assists in preventing warpage. On the other hand care should be taken not to remove the piece from the bath when it is too hot, for internal expansion from the interior which, to a certain point is bound to be hotter than the outside will cause cracking, spalling or warping. Allow the quench to proceed to the point where all vibrations have apparently ceased, then place the tips of the fingers down in the bath and on the piece, and at the point where it can just be touched

but not held without discomfort, it should be removed and either drawn or otherwise "let down" as described.

#### MACHINING STRAINS

Another cause of cracking or warping is machining strains and while this condition is not very common, it is one which should be recognized as very aggravating, for it is likely to occur in the most expensive tool or where considerable amount of machining has been done. As an added insurance against trouble from this source, certain tools, should have the machining strains properly relieved by heating and cooling before hardening is attempted.

Cracking and failure in service are generally the inevitable results of over-heating or under-heating by hardening too close to the critical point. With our present facilities and sources of information the former is hardly excusable while the latter can be avoided by the proper care and attention on the part of the hardener. Failures from over-heating are readily discovered by observing the grain size in the fracture, while those from a quench too close to the critical are more difficult of detection by the naked eye, are readily found by the microscope. A piece which is quenched too close to its critical, while the fracture may appear normal to the unaided eye, is weak and its hardness breaking-down point is lowered. As an illustration of this condition; sometime ago a failure of a tungsten steel chaser die was reported; investigation developed the fact that on hardening from 1480 degrees Fahr. the dies passed the required file and scleroscope tests but on drawing at 375 degrees Fahr. (25 degrees below the established standard) the tools developed softness, and on test the teeth broke out. From the claimants point of view there was something radically wrong with the steel, as their treatment so far as they knew, was an established standard with them over a long period of time and the trouble had never occurred before. The answer to the problem was in the fact that they had not checked their pyrometers, and when this was done, it was developed that for some unaccountable reason they were registering from 20 to 40 degrees Fahr., low. When this was corrected the trouble was overcome, and the drawing could be done at 400 degrees Fahr., as before.

During the course of investigating, it was also demons-

trated, that the steel had a hardening range of about 150 degrees Fahr., and to avoid a reoccurrence of the trouble, the hardening temperature was raised to 1525 degrees Fahr. Similar troubles namely, weakness and loss of hardness below the normal breaking-down temperature will manifest themselves in almost any steel, even high-speed steels. The danger point in these steels apparently is located somewhere between 2000 and 2200 degrees Fahr. While we are informed that the transformation points for high-speed steels are considerably below this range, there is very substantial evidence that a most important change occurs in the modern standard steels, between 2000 and 2200 degrees Fahr.

While on the subject of high-speed steels, it is necessary to mention the fact that a considerable proportion of troubles are caused by the hardener's ignoring or rather failing to recognize the fact that high-speed steels are sensitive to the time element, as they are subject to rapid grain growth at temperatures in excess of about 2000 degrees Fahr., or during the superheat. For this reason the superheat should be as rapid as possible to be consistent with uniformity. Maintaining the superheat from 50 to 75 degrees Fahr., or even higher, over the intended quenching temperature, and quenching when a uniform sweat has appeared on the cutting surfaces, will greatly assist in reducing the time element.

The question is frequently asked, how can one identify the proper quenching temperature for high-speed steels? This is difficult to answer, as differences in analysis affects this point. However, for the standard 16 to 18 per cent tungsten steels, a quench from 2300 to 2350 degrees Fahr., (tool temperature) seems to be the best, while for the lower tungsten or special high-speed steels, temperatures somewhat lower should be used. These lower tungsten steels are not at present in general use, so it seems unnecessary to dwell upon this feature further. Should anyone be interested in them, the writer as far as experience enables him will be glad to answer questions regarding them. The fact remains that many plants have not the pyrometer equipment for measuring high temperatures, at which high-speed steels have to be quenched, consequently the bare fact that 2300 to 2350 degrees Fahr. is productive of best results means little or nothing to them. The following hints will, it is hoped, assist in finding the proper

temperature. Prepare a few sample discs or pieces of the steel as nearly uniform in shape and size, as possible. Preheat these uniformly to a temperature of anywhere from 1500 degrees to 1800 degrees Fahr. Be sure that a neutral or nonoxidizing atmosphere exists in the superheat and quench from various temperatures as shown by the varying intensity of sweat from where it first appears up to the blistering point. Fracture these pieces and note between which points the maximum refinement of fracture is obtained. Then draw the pieces thoroughly to 1100 degrees Fahr. and test with a sharp file.\* Those pieces which are soft indicate too low a quench and by this elimination the ones which are hard and still show the finest fracture are those which have been quenched inside the correct range for the steel.

Most high-speed steels are greatly weakened if they are blistered, and this condition must be avoided, if maximum results are to be obtained. A properly hardened high-speed steel tool should never show scale holes, rough or so called 'alligator skin' surfaces.

For very heavy sections or complicated tools, and those where loss in size must not occur, heating in these stages is most desirable, though not absolutely necessary. First a very thorough preheat between 1400 to 1500 degrees Fahr. or below the scaling point, second an intermediate heat between 1700 to 1800 degrees Fahr. from which the tool should be transferred to the final or superheat just as soon as it has attained the heat of the intermediate furnace, and before scale has had a chance to form. It should always be borne in mind, that excessive scaling is likely to result in blisters, soft surface and is certain to result in loss of size.

The essential precautions to observe when treating high-speed steel tools are thorough preheating, prevention of scaling as much as possible by a proper manipulation of the furnaces, a quick high superheat, hot quenching medium and a thorough drawing as soon as possible after hardening.

It frequently happens that a hardener, who has not been accustomed to handling them runs into trouble when he is first introduced to a chromium, chromium-tungsten or tungsten tool steel, unless he knows something regarding the nature of these

\*If test for hardness is made on the black surface it will be misleading. Either grind spot or test on a fresh fracture.

alloys. The introduction of either one or both of these elements raises the critical points and consequently the quenching temperature, and increases the density of the metal, and therefore the tool made from these steels must necessarily have more time in the fire to insure uniformity throughout. While information is readily available just how to treat these alloy steels their nature can be better understood by the hardener, if he will follow the practice of personally experimenting on some small test pieces to firmly fix in his mind the temperature range and other conditions through which maximum hardness and grain refinement takes place. This is far more economical than experimenting on expensive tools.

#### CRITICAL QUENCHING SPEED

Every different variety of steel has what might be termed its 'critical quenching speed,' that is the speed at which it is necessary to reduce its temperature in cooling through the Ar point and which will result in the maximum degree of hardness. Thus, while it is most desirable to quench carbon and some of the alloy steels as rapidly as possible to hold the carbide or carbides in solid solution, there are certain steels where the addition of such elements as chromium, manganese, tungsten, vanadium, either singly or in combination acts as a brake in preventing this transformation from taking place, in fact there are some of these steels among the chromium steels, those containing 6 per cent chromium, high chromium-tungsten such as air hardening, or high-speed steels, certain combinations of chrome-nickel and certain high manganese steels where a comparatively slow cooling from temperatures above those at which carbide solution takes place (critical point), will result in the lowering of the conversion point on cooling to such an extent as to give a high degree of hardness. As none of the alloy steels will harden to any great extent unless carbon is present in the steel, the obvious conclusion is reached that this so called, 'lowering' action is due to the effect of the combined alloy tending to hold in solid solution, the dissolved carbides. Though it may in some cases be difficult, practically all these alloys can be softened by annealing. It is also known that most of these alloys can be suitably hardened in oil, the quenching speed of which is slower than water or brine, and practically all of them will crack when quenched in water or brine, also

some when certain kinds of oil are used for it is a fairly well known fact, that all oils do not quench with the same speed.

### QUENCHING SPEED

The question of quenching speed is brought forward because of the theory which the writer is convinced is erroneous, and which seems to have some degree of popularity in many places namely that, 'the more rapid any steel, regardless of its composition, can be quenched the greater will be the resulting hardness.' Thus one sometimes finds steels which should be quenched in oil, being hardened in either very thin oil, water or brine in attempting to increase the hardness. The evidence seems to be very conclusive that inasmuch as the critical quenching speed is influenced by the composition of the steel, it is necessary to quench it in a medium which will cool it with a velocity either equal to or slightly in excess of this critical quenching speed, and when this condition has been satisfied, any increase in the velocity of quench by changing the quenching medium will not result in any greater degree of hardness, but more than likely in contraction cracks and in any event, weakness. Thus it follows that oil or self hardening steels must not be quenched in water, or any other medium which will increase the cooling velocity beyond the danger point. If consistent cracking is experienced, this feature should be thoroughly investigated as it is known that different oils will vary in the speed with which they quench, and water sometimes finds its way into the oil tank. The writer has purposely concentrated on the effect of quenching speed as he is convinced from his own experience and that of others, that troubles from this source are of frequent occurrence.

### SOFT SPOTS AND SIMILAR TROUBLES

Soft surfaces, soft spots, and some other undesirable results such as size change, generally are due to the practice of improper heating. It must be borne in mind, that scale is an oxide, and oxygen has affinity for carbon, when the temperature is sufficiently elevated. Thus, a tool which is badly scaled by either, an oxidizing furnace atmosphere or excessive soaking, generally develops

a more or less decarburized and consequently soft surface. Though the soaking at scaling heats may not be sufficiently prolonged to result in actual decarburization there is danger of sections of scale adhering to the surface, and acting as insulators in the quench, resulting in soft spots underneath. Cold tongs, hooks, etc., are also potent causes of soft spots and while their use is generally necessary a little judgment and discretion will indicate a portion of the tool where extreme hardness is not of paramount importance and where it can be held with the tongs or hook with impunity. Do not allow the tool to remain stationary in the quench thus giving the water time to form steam pockets which will not only insulate that portion of the tool where they are formed, but will in many instances result in fracture. The piece should be kept in motion; where there are deep depressions to be hardened, a forced stream should be directed on or in these depressions. If a rehardening is necessary it should be proceeded by a thorough anneal to remove the effects of previous treatment. Lack of attention to this precaution is likely to result in failure if not in total loss of the tool.

The prevention of excessive size change is best accomplished by the use of a nondeforming steel, where it will meet the working conditions. As most steels are subject to an increase in specific gravity, by hardening they naturally shrink. Where shrinkage must be held to the lowest possible degree and a nondeforming steel is not used, the tool should be thoroughly preheated between 1250 to 1350 degrees Fahr. and from this point as rapidly as possible to the desired quenching temperature. By a proper regulation of both furnaces this can be accomplished uniformly and without considerable loss of size or other undesirable condition from scaling.

Grinding which is such as to raise the temperature above the breaking-down point will naturally result in skin softness and frequently in cracks. This may be remedied by a free cutting wheel, light cuts and at proper speeds, which good practice has shown should vary according to whether the steel is carbon or high-speed. One abrasive wheel maker, recommends for the best results, a somewhat coarser and softer wheel, and if possible slightly decreased speeds for high-speed and other very hard alloy steels, than are generally used for carbon or other similar steels.

## DRAWING

Even if a tool has reached this stage in its development where it is to be finish-ground without showing any defect, it does not necessarily follow that it will work to the best advantage, if the drawing has not been correctly accomplished for the class of work which the tool is to come in contact. As indicated before, the operation of drawing, has a major influence on the final results obtained. No hard and fast rule can be laid down for governing this operation for all varieties of work, as this can only be determined by experience and the careful observation of the way in which the tool fails. Suffice it to say that many a tool and many a good tool steel has been discarded for a certain purpose as being too soft, when exactly the reverse has been the case. A rounded or turned over cutting edge does not always signify that the tool is soft, because the tools often attain this condition when too hard, by minute crumbling at the edge, due to the rubbing action of the work, giving them the appearance of being too soft. When a tool fails and it is known that the hardening conditions have been correct, raising the drawing temperature in many cases will remedy the trouble.

## CONCLUSION

Finally, to sum up the text of this paper, it has been shown that tool room troubles can be greatly reduced if not entirely eliminated by:

1. The proper selection of the steel.
2. The proper design of the tool avoiding sharp corners, and adjacent thick and thin sections as far as possible.
3. Co-operation between hardener and designer.
4. Good, though not necessarily expensive, hardening room equipment.
5. Uniform heating and quenching.
6. Drawing to relieve strains as soon as possible after quenching.
7. Knowing the hardening range of the steel and keeping well within it.
8. Not attempting to increase the hardness of a self or

oil-hardening steel by using a cooling medium of greater velocity than that in which it is designed to be cooled.

9. Using preheats wherever possible.

10. Where a large amount of machine work has been done, or warping is likely, annealing before hardening, to relieve machining strains, and annealing if rehardening is necessary.

11. Avoid scaling which will result in loss of size, appearance of soft spots, etc.

12. Proper grinding practice.

13. Drawing to the degree which will produce the toughness necessary to best accomplish the work for which the tool is designed.

## THE ANNEALING OF SHEET STEEL

*(Continued from Page 139)*

stock must be reannealed after cold rolling to remove the strains of cold working. This second annealing operation is very important with light gage sheets, on account of the high phosphorus content. While it might be again said that the correct temperature would be 1620 degrees Fahr., these sheets, now with a high polished surface will stock or weld together much more easily, and since this added expense has been put upon them, loss from stickers will amount to considerably more in money. Experiments showed that on this class of material a temperature of over 1150 degrees Fahr. would cause stickers, and that 1200 degrees Fahr. or over made them impossible to separate. Therefore, the second annealing is very light and it is impossible to remove all strains unless they were annealed in very thin packs, where their weight would not hold them close enough to stick. The roof temperature on cold rolled material does not run over 1400 degrees Fahr. and the firing time about 8 hours.

## BLUE ANNEALING

Heavy gage sheets (sheet mill material) are ordinarily spoken of as blue or box annealed. In this sense, blue annealed means the open annealing of a sheet in an open furnace, the sheet always having considerable scale on it. Blue annealing by the box method is quite a different thing, and as a large tonnage of light gage stock is marketed this way the annealing of it is important. The purpose of blue annealing is to cover the surface of the sheets with a rust-resisting coating of oxide, which being in the form of  $\text{Fe}_3\text{O}_4$  will vary from a light blue to a black. The material may be made as stove pipe, elbow, or high polished stock, with numerous grade between.

Most of the methods for blueing take place during the annealing operations and are so closely related that a study of one must include a study of the other. The author has experimented with some twenty-one methods of obtaining a blued sheet by air, gas, steam and chemicals. The results, however, of these tests are not incorporated in this paper. These few words on blueing

are merely to bring to the readers attention the importance of annealing in the sheet steel industry.

#### SUMMARY

In summing up this paper the contents may be briefly classified into the following 14 points.

1. The most common type of annealing equipment is the box type furnace and annealing boxes.

2. The continuous box type furnace gives better heat control.

3. The continuous muffle type furnace should show a considerable saving in fuel due to the fact that there would be no heat wasted in heating covers and bottoms.

4. Pyrometers on roof work require rare metal couples and the method of measuring temperature within the box is expensive and unsatisfactory.

5. Softness of the sheet does not necessarily mean good stamping quality.

6. A dirty surface will cause a well annealed sheet to break in stamping.

7. Steel should be as low as possible in sulphur and phosphorus with carbon and manganese within reasonable limits.

8. Grain growth must be prohibited even at the expense of incomplete removal of rolling strains.

9. Sticking is the result of a high annealing temperature, and frequently is accompanied by grain growth.

10. The heat distribution in the cannon ball furnace is good, but charging of the boxes is difficult.

11. The bench type furnace, while easy to charge, exhibits poor heat distribution.

12. Stoker-fired furnaces are as economical as hand-fired furnaces.

13. Bringing up the temperature as rapidly as possible will help to clear the sheets. The heat absorption of steel is a definite quantity with time and temperature the main factors.

A high furnace temperature only burns up the furnace and covers.

14. Deoxidizing and blueing are operations carried out on the steels while in a heated condition.

## NOTES FROM THE BUREAU OF STANDARDS

THE FORM OF OXYGEN IN STEEL DETERMINED BY VACUUM FUSION  
ANALYSIS

PREVIOUS tests have indicated that oxygen existing in iron or steel as iron oxide or silica is completely determined by the vacuum fusion method of analysis for gases in metals. Additional tests have been made with oxides of manganese and aluminum, the results showing a recovery of over 90 per cent of the oxygen in either of these oxides, the oxides used in such tests being in comparatively coarse particles.

It has been shown, both in these tests and by previous investigators, that the reduction of such oxides by carbon is more complete the finer the oxide. It is, therefore, believed that such oxides contained in steels as very fine inclusions are completely reduced in the vacuum fusion method of analysis.

## NICK-BEND TESTS OF WROUGHT IRON

Previous work on this subject by the Bureau has shown that the character of the crystalline areas which are often obtained when wrought iron bars are fractured by the nick-bend test is determined largely by the relative size and distribution of the slag threads. In general the smaller the slag threads and the more uniformly they are distributed, the greater is the tendency for crystalline areas to occur.

In order to confirm this tentative conclusion, considerable attention has been given to the nick-bend test of open-hearth iron. It was noticed that the full-sized bars broken in the regular manner of the nick-bend test invariably gave crystalline fractures. The observations previously made on the difference in the nature of the crystalline break on the tension and compression sides of the bar were also confirmed. On the other hand, a large number of the small impact specimens cut from such bars and tested by the Izod and Charpy methods gave silky fractures. Evidently, the nick-bend test should not be considered merely as an impact test of the Izod and Charpy types on a large scale.

By annealing impact specimens of the open-hearth iron at high temperatures up to and including 1150 degrees Cent., which renders the grain size larger and more uniform, the fractures obtained in the impact test were very similar to those in the simple nick-bend test of the untreated iron. However, some of the bars annealed at high temperatures still showed a silky fracture after the Charpy impact test. It appears probable, therefore, that the resistance of the iron to

shock is not determined simply and wholly by the grain size; but that other features, such as the form of the grain, particularly the character of the junction between neighboring grains, may affect the results. Microscopic examinations of fractured specimens are being made to throw light upon this.

#### CRYSTALLINE FORM OF ELECTRODEPOSITED METALS

A paper entitled "Notes on the Crystalline Form of Electrodeposited Metals" has been prepared by members of the Bureau's staff for presentation at the fall meeting of the American Electrochemical Society. The purpose of this paper is to present a simple theory on the mechanism of electrodeposition and a classification of structures which the Bureau believes will be helpful in further studies in this field.

#### THE QUENCHING OF OIL-WATER EMULSIONS ON GAGE STEEL

Considerable time was devoted during the month of June to a study of the characteristic behavior of an oil-water emulsion (a mixture used commercially to some extent) as a quenching medium in the heat treatment of steels.

It was found necessary to stir the mixture with high pressure air to obtain a homogeneous emulsion in which condition it was very stiff and cooled the specimen much more slowly in the upper temperature range than oil. It had the peculiar property of cooling slowly half way and then very rapidly, the time to cool to one-tenth of the temperature range being about the same as for oil. This unique property is evidently due to entrapped air and should be studied further. When completely emulsified, it was not possible to harden standard cylinders of 1.4 per cent chrome steel though they could be hardened if the mixture was not thoroughly emulsified.

#### ADDITIONAL FOUNDRY EQUIPMENT

Up to the present time, nearly all the work of the Bureau's foundry has been limited to the preparation of nonferrous alloys. Recently the Bureau has purchased a small cupola to be used for investigational purposes in connection with the ferrous alloys and also to provide metal for castings used by the Bureau and other branches of the government. During the month of June the construction of a charging platform and foundations for the cupola were completed. The installation and lining of the cupola are now in progress and the equipment will soon be ready for service.

## The Question Box

A Column Devoted to the Asking, Answering and Discussing  
of Practical Questions in Heat Treatment — Members  
Submitting Answers and Discussions Are Requested  
to Refer to Serial Numbers of Questions

### NEW QUESTIONS

QUESTION NO. 88. *What are the flash and fire points of the principal vegetable, animal and mineral oils?*

QUESTION NO. 89. *What are the melting points of the principal chemical elements?*

QUESTION NO. 90. *Please give the temperatures and corresponding temper colors used in the drawing of carbon steel.*

QUESTION NO. 91. *Please state the temperatures and corresponding colors used in hardening carbon steel.*

QUESTION NO. 92. *What is meant by reduction of area in tensile testing of metals?*

### ANSWERS TO OLD QUESTIONS

QUESTION NO. 69. *Is sulphur up to 0.10 per cent detrimental to the quality and physical properties of an automotive steel?*

QUESTION NO. 72. *What elements are conducive to good electric butt-welding of steels?*

QUESTION NO. 73. *Does electric butt-welding destroy the physical properties developed in a steel which has been heat treated prior to the welding operation?*

QUESTION NO. 74. *Why shouldn't a bar of steel rolled from a locomotive axle be better than one rolled direct from the billet made from the original ingot?*

*QUESTION NO. 83. In annealing high-carbon tool steel in an open-fire furnace 6' x 12' is it likely that sulphur would be imparted to the steel by the use of producer gas made from coal unusually high in sulphur, say around 1.50 to 2.00 per cent?*

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*QUESTION NO. 85. What is the best method of preventing carburization in holes, or in the bore of parts to be case hardened?*

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*QUESTION NO. 86. Can ingotism in steel be removed by subsequent rolling or forging?*

ANSWER—By M. H. Medwedeff, metallurgist and chemist, Wyoming Shovel Works, Wyoming, Pa.,

Ingotism in steel is not such a rare phenomenon as it is commonly supposed, particularly in alloy steels made in large open-hearth furnaces and poured into large moulds. But the bad effects of ingotism, i. e., the inherent weakness due to an excessively large grain, are easily overcome by subsequent rolling or forging at proper temperatures.

Ingotism in steel is the phenomenon of an excessively large grain in the cooled ingot. This occurs whenever the solidification range is very wide, i. e., when the pouring temperature is too high, or in general whenever the passage through the solidification has been too slow.

In rolling at proper temperatures, above the critical range, the mechanical work crushes the large crystals which are immediately reformed into smaller crystals. The final size of the crystals will depend upon the finishing temperatures. If the work was stopped when the steel was slightly above the critical range the steel would have a fine grain and the physical properties of the erstwhile brittle steel would be very good. Careful forging will also remove the effects of ingotism.

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*QUESTION NO. 87. What is the reason for the distortion of gears made of S. A. E. 3120 steel after carburizing according to recommended heat treating practice of the S. A. E.?*

ANSWER. By James Sorenson, metallurgical engineer, Four Wheel Drive Auto Co., Clintonville, Wis.

One of the primary causes for gears made from S. A. E. 3120 steel distorting after carburizing is due to the gear blanks

not being thoroughly annealed before carburizing, fluctuation of temperature during the carburizing operation or the use of too drastic a quenching medium in the hardening operation, may also be the cause.

The writer has handled a great many tons of gears made from S. A. E. 3120 steel in the following manner and has always had very good results, both as to uniformity in hardness and structure and a minimum amount of distortion.

The treatment is as follows: After machining of gear blanks anneal at a temperature of 1550 degrees Fahr. and cool in the furnace, finish machine and carburize at 1650 degrees Fahr. Cool in boxes. Reheat to 1575 degrees Fahr. and quench in oil. Reheat to 1450 degrees Fahr. and quench in oil. Draw temper according to the desired hardness of the case.

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ANSWER—By M. H. Medwedeff, metallurgist and chemist, Wyoming Shovel Works, Wyoming, Pa.

Gears will distort during the carburizing process due to various causes. Sometimes excessive distortion will result from improper packing of the gear in the carburizing boxes, i. e., uneven distribution of weight of gear surface. Distortion will also result if the carburizing boxes are unevenly heated, due in turn to faulty furnace operation. The writer has often observed portions of carburizing boxes red hot while other portions are almost black.

Gears should be packed in such a manner that the weight is evenly distributed. Another very common source of distortion is when gear blanks have not been properly annealed and the large forging strains not removed.

To minimize distortion in gears the furnace charge should be brought up slowly to the desired carburizing temperature, and the burners manipulated in such a manner that the furnace chamber is evenly heated. This is very simple if the operators are trained in proper adjustment of burners. It is really remarkable how little attention is paid to this point. It is also important to allow the gears to cool in the boxes until black.

Uneven heating and faulty distribution of weight of gear in quenching will also cause distortion.

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In the July issue of TRANSACTIONS, Question No. 76 was answered by B. F. Weston of the Jones & Laughlin Steel Corporation. It was stated that Mr. Weston was located at the S. S. Works, Beaver Falls, Pa. This statement should have been South Side Works, Pittsburgh, Pa.

# ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective

## NEW MEMBERS

- ALLISON, A. R., (Jr-6), 58 Chestnut St., Lewistown, Pa.  
 BARTLETT, C. F., (M-4), Box 350 Redford, Mich.  
 BECK, F. A., (M-6), 4636 E. Thompson St., Philadelphia, Pa.  
 BENDIXON, H. H., (Jr-7), c/o Bettendorf Co., Bettendorf, Iowa.  
 BOLTON, H. L., (M-6), Beacon Oil Co., Everett, Mass.  
 BRUNNER, E. H., (M-6), 621 Fourth Ave., Bethlehem, Pa.  
 CAMPBELL, L. A., (M-3), 1041 W. Forty-eighth St., Los Angeles, Cal.  
 CANDLIN, WALTER, (A-5), 5034 Tamson St., Philadelphia, Pa.  
 CANN & SAUL STEEL CO., (S-6), 516 Commerce St., Philadelphia, Pa.  
 CARLSON, J. V., (M-5), Union Special Machine Co., Chicago, Ill.  
 CASLIN, JAMES, (M-6), 5923 Romania Place, St. Louis, Mo.  
 CLAYPOOL, W. L., (Jr-7), Bettendorf Co., Bettendorf, Iowa.  
 CLEMENT, H. L., (M-5), Union Special Machine Co., Chicago, Ill.  
 DEANE, H. A., (Jr-7), 1183 Twenty-fifth St., Moline, Ill.  
 DENNY, A. B., (M-3), Llewelyn Works, Torrance, Cal.  
 ELLIS, O. W., (M-6), Dept. of Met., University of Toronto, Toronto, Ontario, Canada.  
 FENTRESS, G. E., (M-7), 2525 Thirty-seventh St., Los Angeles, Cal.  
 FRAUNTHAL, A. H., (M-4), 998 Parkwood Drive, Cleveland, O.  
 FUREY, CORNELIUS A., (M-5), 2620 S. Sixteenth St., Philadelphia, Pa.  
 GILCH, JOHN A., (M-6), 305 Van Vranken Ave., Schenectady, N. Y.  
 GOODENOW FURNACE CO., F. J., (S-4), 2153 Warren Ave. W., Detroit, Mich.  
 HOTCHKISS, R. M., (M-6), 263 Park St., New Haven, Conn.  
 HYBINETTE, V., (A-6), Hotel Dupont, Wilmington, Del.  
 KINNEY, L. W., (M-6), 18100 Cornwall Rd., N. E., Cleveland, O.  
 LA VAN, MONT, (M-6), Mechanics Machine Co., Rockford, Ill.  
 LEWIS, H. R. Jr., (M-6), Ohio Seamless Tube Co., Shelby, Ill.  
 LIGHTFOOT, H. A., (M-5), 1633 Dyre St., Frankford, Philadelphia, Pa.  
 LOVELL, A. C., (M-7), Fabric Tool Protector Co., South Bend, Ind.  
 MAXFIELD, T. C., (A-6), E. F. Houghton & Co., New York City.  
 NICKLE, H. D., (M-5), 532 Beacon St., Boston, Mass.  
 PEARNE, F. Y., (M-3), 209 E. Ave. 55, Los Angeles, Cal.  
 PIRK, G., (Jr-7), General Electric Co., Schenectady, N. Y.  
 RADFORD, V., (M-7), National Malleable Castings Co., Sharon, Pa.  
 REEVES MFG. CO., (S-6), Milford, Conn.  
 ROSS, J. G., (M-7), 1036 S. Main St., Waterbury, Conn.  
 SOVERHILL, H. A., (M-5), 1120 Thirteenth St., Moline, Ill.  
 SZEKELY CO., C. O., (S-7), Sixth Ave., Moline, Ill.  
 TREANOR, J. D., (Jr-6), 416 Eighteenth Ave., Moline, Ill.  
 VIERIECK, A. L., (M-5), 224 S. Pine St., Davenport, Ia.  
 WALLEN, E. A., (M-6), Bellis Heat Treating Co., New Haven, Conn.  
 WARD'S SONS CO., EDGAR T., (S-6), Sixteenth St., and Indiana Ave., Philadelphia, Pa.  
 WEBSTER, G. W., (Jr-7), 583 Central Ave., New Haven, Conn.  
 WOOD, LEON G. S., (Jr-6), Saco-Lowell Shops, Lowell, Mass.

## CHANGES OF ADDRESS

- ADAMS, H. R., from 816 W. Lake Street, to 1302 W. Washington Blvd., Chicago, Ill.
- ADAMS, J. O., from 930 Church St., to E. C. Atkins Co., Indianapolis, Ind.
- BODINÉ, FRANK, from 2303-14th Ave., to 1312 Seventh St., Rockford, Ill.
- BURKE, THEODORE, from Isaac G. Johnson Co., Spuyten Duyvil, N. Y., to Otis Elevator Co., Buffalo, N. Y.
- CHABOT, J. M. T., from 23 Silver St., Waterville, Maine, to 115 Court St., Charleston, W. Va.
- CINIOTTI, G. E., from 726 N. Beatty St., Pittsburgh, Pa., to Vanadium Alloys Steel Co., Springfield, Mass.
- COLLINS, ARTHUR L., from 5616 Crowson St., Germantown, Pa., to Horace T. Potts & Co., Philadelphia, Pa.
- CONRADI, L. C., from R. F. D. No. 1, to 143 Jackson Ave., Plainfield, N. J.
- CORNISH, F., from 3 Greenwood Ave., to 288 Vernon St., Blue Island, Ill.
- CRAMP, ARTHUR L., from Imperial Drop Forge Co., to Route "C," Box 393, Indianapolis, Ind.
- DAY, WM. E. Jr., from 311 Magnolia St., to International Motor Co., New Brunswick, N. J.
- ESAU, G. W., from 6739 Cornell Ave., to E. F. Houghton & Co., Chicago, Ill.
- FISCHBECK, H. J., from 137 Twenty-second St., Irvington, N. J., to Pratt & Whitney Co., Hartford, Conn.
- FREDERICK, J. B., from Poole Hotel to Barber Colman Co., Rockford, Ill.
- GARDNER, G. E., from 2278 Detroit Ave., to 1309 Palmetto, Toledo, O.
- GILMOUR, M. L., from Reynolds Wire Co., to 2007 Everett St., Houston, Texas.
- GRIFFITHS, E. M., from Universal Steel Co., Bridgeville, Pa., to 348 W. College St., Canonsburg, Pa.
- HARTMAN, Wm. C., from 425 Avenue B, Bethlehem, Pa., to 616 S. Catalina Ave., Redondo Beach, Cal.
- HEISE, A. R., from New Departure Mfg. Co., to General Delivery, Bristol, Conn.
- HERB, J. W., from 729 Washington Street, Easton, Pa., to 98 Washington St., Phillipsburg, N. J.
- HINDE, WILFRED, from Y. M. C. A., Moline, to 638 Forty-third St., Rock Island, Ill.
- HOAGLAND, F. O., from Reed-Prentice Co., Worcester, Mass., to Saco Lowell Shops, Lowell, Mass.
- HOGAN, E. J., from 2609 N. Main St., to Box 1227, Hughes Tool Co., Houston, Tex.
- HOWE, H. A., from 4870 Edmonton Ave., Detroit, to 2218 W. 11th St., Terre Haute, Ind.
- JARDINE, ROBT., from Rich Tool Co., Chicago, to 709 Kresge Bldg., Detroit, Mich.
- JONES, A. R., from 425 E. Water St., Milwaukee, to Interstate Iron & Steel Co., 1401 Monroe Bldg., Chicago, Ill.
- JONES, R. H., from 1400 Portland Ave., to 3016 29th Ave. S., Minneapolis, Minn.
- KRUMM, S. Z., from Case School of Applied Science to 4912 E. 84th St., Cleveland, O.
- LASCHUK, S., from 733 S. Karlov Ave., to 1644 Augusta, Chicago, Ill.

- MACKENZIE, Wm. J., from 5437 University Ave., to Interstate Iron & Steel Co., Chicago, Ill.
- MAGILL, B. H., from 520 Campbell Ave., to 13 Osteltz Ave., Schenectady, N. Y.
- MAHLIE, C. C., from 1927 Waldeck St., Columbus, O., to American Rolling Mill Co., Middletown, O.
- MARINO, F. P., from 2437 Emerson Ave., to 5248 29th Ave. S., Minneapolis, Minn.
- McANIFFE H. F., from 80 Lilac St., Buffalo, N. Y., to Stanhope, N. Y.
- McARDELL, W., from 15 Argyle Rd., Brooklyn, N. Y., to 445 Richmond Rd., Staten Island, N. Y.
- McGUIGAN, R. J., from 5539 Baywood St., Pittsburgh, Pa., to Birch Lynn, Wheeling, W. Va.
- McMANNUS, W. H., from 50 Peterboro St., to 4417 Second Ave., Detroit, Mich.
- OBERHELLMAN, T. A., from 2801 LaSalle St., to 1075 Arcade Bldg., St. Louis, Mo.
- REDDERSON, E. W., from 6909 S. Green St., Chicago, Ill., to 2245 Blaine Ave., Detroit, Mich.
- RINEHART, H. F., from Curtis & Co., Mfg. Co., to Chevrolet Motor Co., St. Louis, Mo.
- SCARBROUGH, H. E., from General Electric Co., to 165 S. Clark St., Chicago, Ill.
- STENGER, BERNARD H., from Queen City Steel Treating Co., to 1620 John St., Cincinnati, O.
- STEPHENSON, R. L., from 964 Stimson Place to 9161 Concord St., Detroit, Mich.
- THUM, E. E., from Chemical & Metallurgical Engineering, New York City, to 34 Aubrey Rd., Montclair, N. J.
- TURNQUIST, E., from 332 W. 9th St., to 303 Brock Apts., Anderson, Ind.
- VIGEANT, X., from 1336 W. Washington Blvd., to 14 E. Jackson Blvd., Chicago, Ill.
- WESTON, B. F., from Union Drawn Steel Co., to 817 12th St., Beaver Falls, Pa.

#### MAIL RETURNED

- KENT, F. E., 101 N. Virginia Ave., Atlantic City, N. J.
- ADRIANCE, E. F., 173 Sante Fe Ave., Huntington Park, Cal.
- ALBRECHT, T. A. L., 67 Massachusetts St., Detroit, Mich.

## Items of Interest

**T**HE many friends and acquaintances of T. E. Barker one of our founder members and past vice president, will be interested to know that he is now associated with the Atlas Steel Corporation as service engineer with offices at 1242 W. Washington Boulevard, Chicago, Illinois.

Mr. Barker's exceedingly active interest in the promotion of better heat treating practice, and his extended experience in the application of steels should make him the welcome guest of all steel users.

We are sure that, after his rather extended sojourn on the frontier, Mr. Barker will be glad to welcome his old friends at the above address.

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Mark Ammon has accepted a position as metallurgist with the Steel Improvement and Forge Company of Cleveland. Mr. Ammon was formerly connected with the Peerless Company of Cleveland, Willys-Overland of Toledo, and more recently with the Earl Motors at Jackson, Michigan.

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C. K. Everitt, works manager and director of Edgar Allen & Co., Ltd., Sheffield, England, is now visiting in the United States.

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Charles M. Schwab had conferred upon him the honorary degree of Doctor of Laws by St. Francis college at Loretto, Pa., June 14. Mr. Schwab graduated from the college in 1881.

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R. W. McPhee, who for the past few years has been with Henry Pels & Co., New York, dealers in plate fabricating machinery, has purchased an interest in the Blackman, Hill, McKee Machinery Co., St. Louis, and will begin his new work July 1.

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E. J. Lowry, metallurgist, Hickman, Williams & Co., as a representative of the American Foundrymen's association, will present an exchange paper on "Semi-Steel" at the convention of the International Foundrymen's association at Paris, France, Aug. 22.

